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DIESEL ENGINE ENDURANCE TESTS USING JP-8 FUEL BLENDED WITH USED ENGINE OIL

INTERIM REPORT
TFLRF No. 330

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13. ABSTRACT

Tests were done to examine the feasibility of disposing of used engine oil from military vehicles by blending it with JP-8 engine fuel to be used in diesel vehicles. Two Army diesel engines were evaluated in cyclic endurance dynamometer test procedures using JP-8 fuel blended with 7.5% vol used oil. Results were compared to baseline performance using neat JP-8 fuel. The following major differences were observed when using blended fuel: Significant ashy deposits were found in the pre-combustion chamber of the 4-cycle diesel engine; indications of imminent exhaust valve burning (streaking) were found on the exhaust valves in the 2-cycle diesel engine. For both engines, condition was such that continuous use of 7.5 %vol blend would not be recommended. Considering it would take between 19-68 years for an Army engine to reach the end of endurance test condition, use of blended fuel 1 or 2 times per year is judged acceptable from an endurance standpoint.

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EXECUTIVE SUMMARY

Problem: Large quantities of used engine oil are generated at U.S. Army installations. Safe, environmentally responsible disposal of the used engine oil is difficult and costly.

Objective: The objective of this investigation was to investigate the reutilization of used engine oil as a fuel blend component in JP-8 fuel for Army ground wheeled vehicles. Diesel engine endurance was determined using the blended fuel.

Importance of Project: If the use of JP-8 blended with used oil would provide acceptable diesel engine endurance, a field portable filtration unit could be used that would remove used engine oil from the vehicle, filter it, blend it with fuel diverted from the vehicle's fuel tank, and return the used oil/fuel blend to the vehicle fuel tank to be consumed.

Technical Approach: The approach was to determine the effects of continuous operation on JP-8 blended with 7.5 %vol filtered used oil in both 2-cycle and 4-cycle diesel engines. The 7.5 %vol blend was selected as a representative maximum level that Army equipment could experience based on vehicle crankcase and fuel tank capacities. Continuous use of the blend was intended to accelerate the effects. Baseline and blended fuel endurance tests were conducted in engines representative of the U.S. Army fleet.

Accomplishments: Two Army diesel engines were evaluated in cyclic endurance dynamometer test procedures using JP-8 fuel blended with 7.5 %vol used oil. Results were compared to baseline performance using neat JP-8 fuel. The following major differences were observed when using blended fuel: significant ashy deposits were found in the pre-combustion chamber of the 4-cycle diesel engine; indications of imminent exhaust valve burning (streaking) were found on the exhaust valves in the 2-cycle diesel engine. For both engines, conditions were such that the continuous use of 7.5 %vol blend would not be recommended. Considering that it would take between 19 and 68 years for an Army engine to reach the end-of-endurance test condition, the use of blended fuel one or two times per year is judged acceptable from an endurance standpoint.

Military Impact: Implementation of this technique to dispose of used engine oil would have two-fold cost savings. The Army would not have to dispose of used oil, and each gallon of used oil consumed as fuel is equal to one less gallon of JP-8 purchased.

FORWORD/ACKNOWLEDGMENTS

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The authors would like to acknowledge the efforts of TFLRF personnel who assisted with this program. Mr. Jack Dozier assisted with the engine operation, and Mr. W.E. Likos provided expert consultation throughout the program. Special thanks are given to Mr. R.J. Holley at Fort Hood, TX, for assistance in supplying the test fuel, Radian, Inc. for assistance in obtaining used oil, and Mr. Ralph B. Mowery at TARDEC for providing overall program direction.

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I. INTRODUCTION AND BACKGROUND

Large quantities of used engine oil are generated at Fort Hood, TX and other U.S. Army installations. Disposal of the used engine oil is difficult and costly. A program is being conducted to determine the feasibility of reutilizing waste engine oil as a blending component in fuel intended for use in ground wheeled vehicles. The ultimate objective is to use a filtration unit that removes used engine oil from the vehicle, filters it, blends it with fuel diverted from the vehicle's fuel tank, and returns the used oil/fuel blend to the fuel tank to be consumed. Participants in the program are the National Automotive Center, TARDEC, Warren MI, the Petroleum and Water Business Area, Warren, MI, III Corps, Ft. Hood, TX, National Training Center, Ft. Irwin, CA, Radian Inc., and the U.S. Army TARDEC Fuels and Lubricants Research Facility at SwRI (TFLRF), San Antonio, TX .

Previous TFLRF efforts began with laboratory evaluations to characterize used engine oil obtained from ground vehicles and equipment at Ft. Hood, TX. Twenty-five individual used oil samples from a wide variety of equipment were analyzed in detail. Wear metal contamination, and fuel dilution were the most prevalent oil degradation modes. None of the 25 samples had extremely high total acid numbers, soot, or insolubles. The effects of various used-oil blend levels on fuel (JP-8) properties were determined. Blends containing greater than 5.0% vol. used oil exceeded the United States EPA allowable sulfur limits for on-road diesel fuel. A trend to destabilization and lowering of fuel quality was observed with increasing used oil content in JP-8. However, the lubricity properties of JP-8 were enhanced with the blends of used oil. (1)

This report describes a test-engine investigation of the impacts of the blended oil/fuel mixture on diesel engine performance and durability.

Future work will include a limited field demonstration of the waste oil reutilization concept at National Training Center, Ft. Irwin, CA, as well as technical support for associated program efforts such as exhaust emission tests.

II. OBJECTIVE AND APPROACH

The objective was to determine the effects of continuous operation on JP-8 blended with 7.5% vol. filtered used oil in both 2-cycle and 4-cycle diesel engines. The 7.5 %vol blend was selected as a representative maximum level that Army equipment would experience based on vehicle crankcase and fuel tank capacities. Continuous use of the blend was to accelerate the effects. Baseline and blended fuel endurance tests were conducted in engines representative of the U.S. Army fleet.

III. TEST FUELS

Ft. Hood, TX supplied JP-8 fuel. The chemical properties of neat JP-8 are presented in Table 1. The U.S. Military specification requirements for JP-8 (2) are tabulated, along with the corresponding properties of the neat JP-8 fuels used at TFLRF. These particular fuels meet all JP-8 fuel requirements critical for diesel engine performance.

Table 1. Properties of Neat JP-8 Test Fuel

Fuel ID Code				AL-12780-F Test 39	AL-24805-F* Test 97-1
Property		**Test Method**	**MIL-T-83133B JP-8/NATO F-34 Requirements**		
Color			a.		
Density, kg/L		D 1298	0.775-0.840	0.7793	
API Gravity		D 1298	37-51	50	44.5
Distillation, °C	IBP	D 86	a.	153	150.5
	10%	D 86	186 max.	160	172.8
	20%	D 86	a.	161	179.7
	30%	D 86		162	187.6
	40%	D 86		163	194.8
	50%	D 86	a.	164	202.1
	60%	D 86		166	210.4
	70%	D 86		167	219.3
	80%	D 86		169	229
	90%	D 86	a.	172	241.6
	End Point	D 86	330 max.	201	262.9
	Res., vol%	D 86		0.3	1
Distillation, °C	IBP	D2887		140.1	
	10%	D2887		153.1	
	20%	D2887		160.2	
	30%	D2887		165.9	

Table 1. Properties of Neat JP-8 Test Fuel					
Fuel ID Code				**AL-12780-F Test 39**	**AL-24805-F* Test 97-1**
Property		**Test Method**	**MIL-T-83133B JP-8/NATO F-34 Requirements**		
	40%	D2887		170.1	
	50%	D2887		173	
	60%	D2887		176.7	
	70%	D2887		179	
	80%	D2887		181.3	
	90%	D2887		186	
	End Point	D2887		215.2	
Flash Point, °C		D 56	38 min.	39	44
Freeze Point, °C		D 2386	-50 max.	-59	
Cetane Number		D 613		40.3	46.9
Kinematic Viscosity at 40°C, cSt		D 445		0.89	1.28
Cu Corrosion, at 100°C		D 130	1B max.	1A	1A
Total Acid Number		D 3242	0.015 max.	0	<0.01
Saturates, vol%		D 1319		80.7	
Olefins, vol%		D 1319		1.4	
Aromatics, vol%		D 1319	25.0 max.	17.9	
Sulfur, wt%		D 2622	0.30	<0.01	0.03
Mercaptan Sulfur, wt%		D 3227	0.001 max.	<0.001	
Saybolt Color		D 156		+26	
Net Heat of Combustion, Btu/lb		D 240	18,400	18,548	18,519
Carbon, wt%		D 3178		85.49+-0.02	
Hydrogen, wt%		D 3178	13.5 min.	14.01+-0.01	
Particulate Contamination, mg/L		D 2276	1.0 max	0.8	
Existent Gum, mg/100 mL		D 381	7.0 max.	0.4	2.5
Water Reaction		D 1094	1B	1B	
Water Separation Index, Modified		D 2550	70 max.	76	
Water Separation Characteristics by Microseparator		D 3948		88	
Fuel System Icing Inhibitor, %		Fed. Std. 791	0.10-.015	0.1	
Electrical Conductivity, pS/m		D 3114	200-600	17	
Ash, wt%		D 482			<0.001
Accelerated Stability, mg/100mL		D 2274			0.4
Lubricity:	HFRR, mm	ISO			0.645
	SLWT, kg	ARMY			2100
a. Report.					
* Analysis was performed on AL-24717-F, from same batch as AL-24805-F but delivered to TFLRF separately.					

The composition and chemical properties of the used oil that was taken from vehicles at Ft. Hood are given in Table 2. Radian, Inc. collected the used oil, with assistance from TFLRF. The used oil was collected from 81 vehicles that had been directed by the Army Oil Analysis Program (AOAP) to change oil. Used oil containing glycol was not collected. The used oil was collected from 61 tracked vehicles and 20 wheeled vehicles, encompassing nine vehicle categories. Samples of the used oil from 25 of the vehicles were selected for detailed analysis. Overall, none of the used oils that were analyzed in detail had extremely high total acid numbers, soot contents, or insolubles contents. The properties presented in Table 2 are the result of analysis done on a sample taken from a composite of all the used oils blended together.

Table 2. Properties of Used Oil Taken From Vehicles at Fort Hood

Sample ID Code			AL-24627-L	AL-24644-L*
Property		**Test Method**		
Viscosity at 40°C, cSt		D 445	82.19	82.19
Flash Point, °C		D 92	207	ND**
Tan		D 664	2.51	ND
Water Content, ppm		D 4928	1910	1760
Pentane Insolubles, wt%		D 893B	0.04	0.05
Toluene Insolubles, wt%		D 893B	0.03	0.04
Gravity at 60°F		D 287	27.8	27.8
Sulfur, wt%		X-Ray	0.6	0.6
Chlorine, ppm		X-Ray	<200	<200
Soot, wt%		TGA	0.5	0.5
Sulfated Ash, wt%		D 874	0.89	ND
Elemental, ppm	Ca	D 5185	1933	1947
	Mg	D 5185	212	210
	P	D 5185	8.78	879
	Zn	D 5185	1004	1013
	Ag	D 5185	<1	<1
	Al	D 5185	12	12
	B	D 5185	85	86
	Ba	D 5185	3	3
	Cr	D 5185	10	10
	Cu	D 5185	67	67
	Fe	D 5185	96	95
	Mo	D 5185	75	75
	Mn	D 5185	3	3
	Ni	D 5185	3	3
	Pb	D 5185	20	21
	Sb	D 5185	<1	<1

Table 2. Properties of Used Oil Taken From Vehicles at Fort Hood				
Sample ID Code			AL-24627-L	AL-24644-L*
Property		Test Method		
	Si	D 5185	45	45
	Sn	D 5185	8	8
	Na	D 5185	15	15
* Oil was filtered (25 micron Fleetguard FF-202 fuel filter) prior to analysis.				
** ND = Not Determined				

The process used to prepare the used oil and blend it with JP-8 is summarized in Table 3.

Table 3. Preparation of Blended Fuel	
Used Oil Preparation:	
	426.7 gallons taken from 81 vehicles as directed by Army Oil Analysis Program
	Mixed with stirrer and recirculating pump, 6 hours
	Sample collected and analyzed immediately after mixing
	All used oil filtered though 25μ Fleetguard FF-202 fuel filter
JP-8/Used Oil Blending Process:	
	Measured amount of filtered used oil put into 55-gal. drum via calibrated measuring can
	Measured amount of fuel added to 55-gal. drum via calibrated flow measuring device
	Contents of 55-gal. drum thoroughly stirred
	Used oil comprised 7.5% of the blend, by volume

Finally, the properties of the resulting JP-8/7.5% vol. used oil blend are presented in Table 4.

Table 4. Properties of Blended Fuel			
Fuel ID Code			AL-24647-F
Property		Test Method	
Gravity at 60°F		D 287	43.2
Distillation, °C	IBP	D 86	153
	10%	D 86	174
	30%	D 86	190
	50%	D 86	206
	70%	D 86	225
	80%	D 86	237
	90%	D 86	266
	End Point	D 86	287
	Recovered, vol%	D 86	93.9
	Residue, vol%	D 86	6.1
Flash Point, °C		D 92	43
Cetane Number		D 613	46.2
Kinematic Viscosity at 40°C, cSt		D 445	1.6

Table 4. Properties of Blended Fuel			
Fuel ID Code			**AL-24647-F**
Property		**Test Method**	
Kinematic Viscosity at 40°C, cSt		D 445	1.6
Cu Corrosion, at 100°C		D 130	IB
Total Acid Number		D 664	0.22
Aromatics, vol%		D 1319	17.5*, [a]
Sulfur, wt%		D 2622	0.08
Net Heat of Combustion, Btu/lb (MJ/kg)		D 240	18,578 (43.21)
Carbon, wt%		D 5291	85.81
Hydrogen, wt%		D 5291	13.72
Particulate Contamination, mg/L		D 5452	14.2**, [a]
Existent Gum, mg/100 mL		D 381	3146.7
Carbon Residue (10% Bottoms)		D 524	1.07
Ash, wt%		D 482	0.064
Accelerated Stability, mg/100mL		D 2274	0.2**, [a]
Interfacial Tension, dynes/cm		D 971	20.8
Lubricity:	HFRR, mm	ISO	0.46
	BOCLE, mm	D 5001	0.71
	SLWT, kg	ARMY	4150***
Water Content, ppm		D 4928	384
Elemental, ppm	Ca	D 5185	143
	Mg	D 5185	17
	P	D 5185	62
	Zn	D 5185	81
	Ag	D 5185	<1
	Al	D 5185	1
	B	D 5185	6
	Ba	D 5185	<1
	Cr	D 5185	1
	Cu	D 5185	6
	Fe	D 5185	8
	Mo	D 5185	6
	Mn	D 5185	<1
	Ni	D 5185	<1
	Pb	D 5185	<1
	Sb	D 5185	<1
	Si	D 5185	3
	Sn	D 5185	<1
	Na	D 5185	4

STMT Test
* Soot came down column and olefin and aromatic separation was not definitive
** Soot was visible on both the control and test filters
*** Increased chatter during non-scuffing

[a] = Test method was designed for distillate fuel. Blended samples are beyond the scope of the test method.

IV. GM 6.2L ENGINE ENDURANCE TESTS

Endurance tests were conducted using the General Motors (GM) 6.2L engine. Test 97-1 was a baseline test, fueled by neat JP-8. Test 97-2 was an experimental test, fueled by a blend of JP-8 and 7.5% vol. used oil.

A. Engine Description

A description of the GM 6.2L engine is presented in Table 5, and a photograph of the engine dynamometer installation is shown in Figure 1. For this evaluation, an engine in the High Mobility Multipurpose Wheeled Vehicle (HMMWV) configuration (145 hp) was used. The GM 6.2L engine is widely used in large numbers in U.S. Army combat and tactical equipment as shown in Table 6.

Table 5. GM 6.2L Engine Specifications

Engine Type:	Naturally Aspirated, Ricardo Swirl Precombustion Chamber, Four-Stroke, Compression Ignition
Cylinders:	8, V-Configuration
Displacement, L ($in.^3$):	6.2 (379)
Bore x Stroke, mm (in.):	101 x 97 (3.98 x 3.82)
Compression Ratio:	21.3:1
Rated Power, kW (BHP):	96.9 (130) CUCV, 107.7 (145) HMMWV
Rated Torque, Nm (ft-lb):	325 (240)
Oil Capacity, L (gal.):	6.62 (1.75)
Engine Structure:	Cast Iron Head and Block (No Cylinder Liners), Aluminum Pistons
Injection System:	Stanadyne DB-2 F/I Pump with Bosch Pintle Injectors

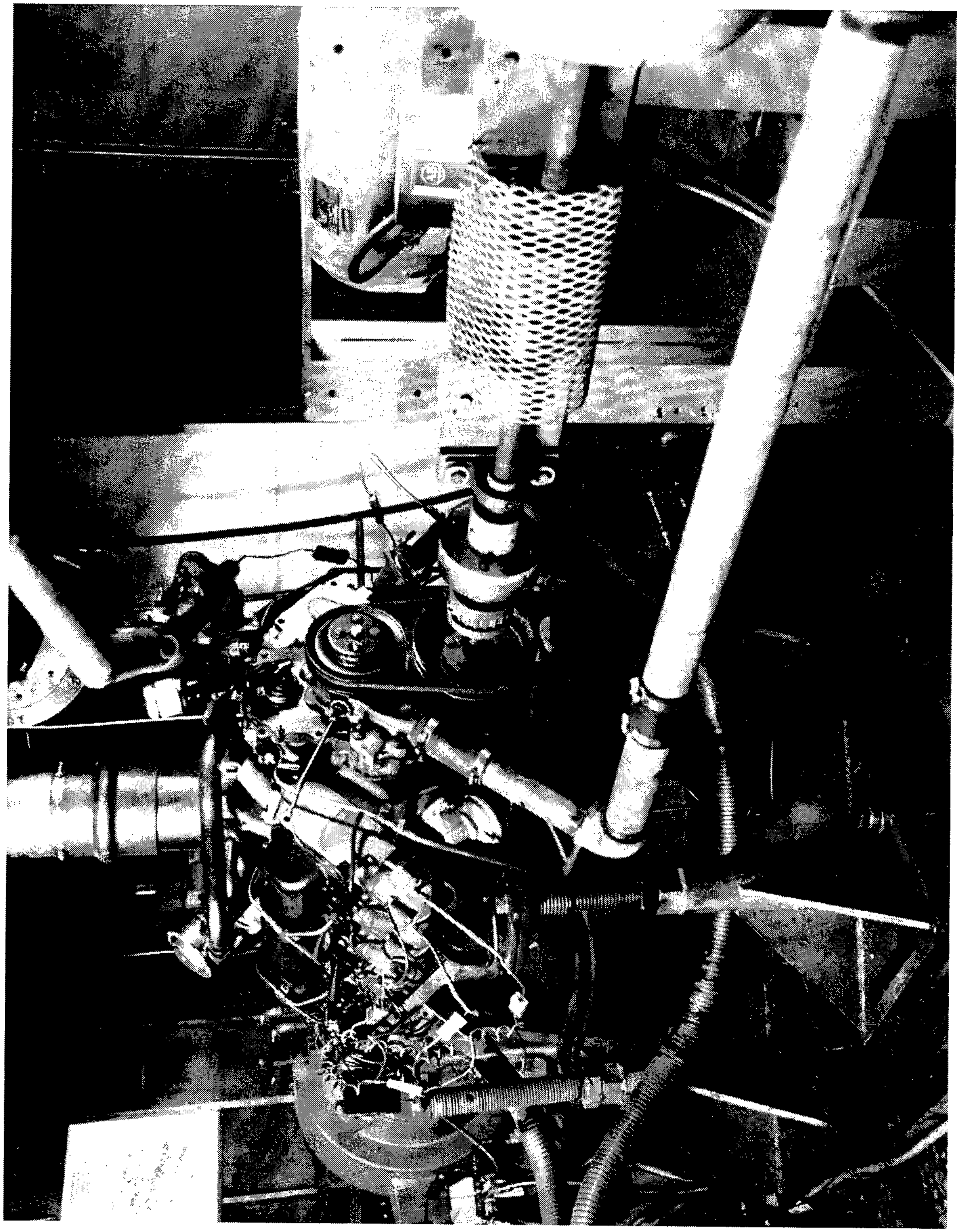


Figure 1. Installation of GM 6.2L Engine

Table 6. U.S. Army Vehicles Powered by the GM 6.2L/6.5L Diesel Engine	
Designation	Description
M996	Truck, Ambulance: HMMWV
M997	Truck, Ambulance: HMMWV
M1010	Truck, Ambulance: TAC, 5/4 Ton
M1008	Truck, Cargo: Tactical, 5/4 Ton, CUCV
M1008A1	Truck, Cargo: Tactical, 5/4 Ton, CUCV
M1028	Truck, Cargo: Tactical, 5/4 Ton, CUCV
M1025	Truck, Utility: 4x4, 1¼ Ton, HMMWV
M1026	Truck, Utility: 4x4, 1¼ Ton, HMMWV
M1038	Truck, Utility: C60, 1¼ Ton, HMMWV
M998	Truck, Utility: C60, 1¼ Ton, HMMWV
M1037	Truck, Utility: S250, HMMWV
M1009	Truck, Utility: Tactical, ¾ Ton, CUCV
M966	Truck, Utility: Tow Carrier, HMMWV
M1035	Truck, Ambulance, HMMWV
M1043A2	Truck, Utility, HMMWV
M1097	Truck, Utility, HMMWV
M1069	Truck, Utility, Light Army, HMMWV
M113	Truck, Utility, S250, HMMWV
M1045A2	Truck, Utility, Tow, HMMWV
M1109	Truck, Utility, Armored, HMMWV
M1114	Truck, Utility, Armored, HMMWV

B. Test Cycle

The engine test cycle used in this portion of the program was a modified version of the Army/CRC 210-hour Wheeled-Vehicle (WV) endurance cycle, shown in Table 7. The test cycle was modified by using blended fuel and by occasionally operating less than 10 periods per day. This was to accommodate TFLRF work schedules. This cycle has been correlated to 32,185 km (20,000 mi) of proving ground experience. (3)

Table 7. Army/CRC 210-Hour Wheeled-Vehicle Endurance Cycle		
Period*	**Time, hr**	**Rack/Throttle Setting**
1	2	5 min. idle followed by slow acceleration to maximum power
2	1	Idle
3	2	Maximum Power
4	1	Idle
5	2	Maximum Power
6	1	Idle
7	2	Maximum Power
8	1	Idle
9	2	Maximum Power
10	10	5 min. idle followed by shutdown
* These ten periods yield 14 hours of running with a 10-hour shutdown; this cycle is repeated 15 times for a total test time of 210 hours.		

C. Lubricant

The lubricant used in the GM 6.2L engine tests was a qualified MIL-L-2104F (4) Army reference oil, with an SAE viscosity grade of 15W40. When batches of this oil were received at TFLRF, they were designated as AL-24610-L and AL-22999-L. A listing of the oil properties and composition is given in Table 8.

Table 8. GM 6.2L Test Lubricant Properties

Sample ID Code		AL-24610-L/ AL-22999-L
Property	ASTM Method	
K. Vis, 40°C, cSt	D 445	109.39
K. Vis, 100°C, cSt	D 445	14.60
Total Acid Number	D 664	1.76
Total Base Number	D 664	5.58

D. Test 97-1, Neat JP-8, Baseline

The 210-hour baseline test using neat JP-8 was completed on 29 March 1997. At 154 hours, the amount of iron wear metal present in the engine oil exceeded guidelines set by the Army Oil Analysis Program (AOAP), and the viscosity surpassed its SAE grade, so the oil was changed.

Disassembly of the engine at the end of the test revealed that several push rods were bent during the test. This was attributed to the inadvertent use of exhaust valves 1.0 mm too large in diameter. The GM 6.2L engine's compression ratio of 21.5:1 dictates a small clearance volume. With indirect injection, or swirl chamber, engines 50% or higher of the clearance volume at top dead center are typically contained in the swirl chamber. The balance of the clearance volume is contained between the piston crown and fire deck. With a 45°-valve seat, the 1mm larger exhaust valves extend an additional 0.707-mm into the cylinders to allow contact with the piston crown during valve closure. This did not affect engine deposit ratings; however, an alternate test was used for baseline wear comparisons. Detailed information (test data and photographs) is presented in Appendix A.

E. Test 97-2, JP-8 + 7.5% vol. Used Oil

The 210-hour test using blended fuel was completed without problem on 23 May 1997. The oil was changed at 154 hours for consistency with Test 97-1. At 115 hours, the load

cell was recalibrated due to unexpected changes in the load. At 120 hours, it was found that the dynamometer rear bearing condition was deteriorating, and subsequent load readings were erratic. This can be seen in Figure 2, where the load over time is plotted for Tests 97-1 and 97-2. Midway through Test 97-2, the load cell began to produce a wide range of loads. From approximately 180 hours until the end of the test, the load cell appeared to function satisfactorily. Detailed information and test data are presented in Appendix B.

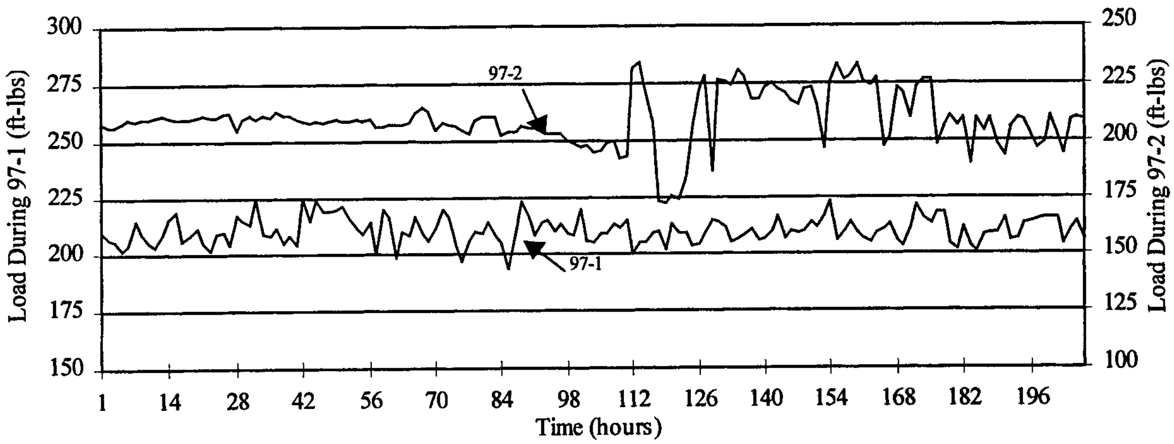
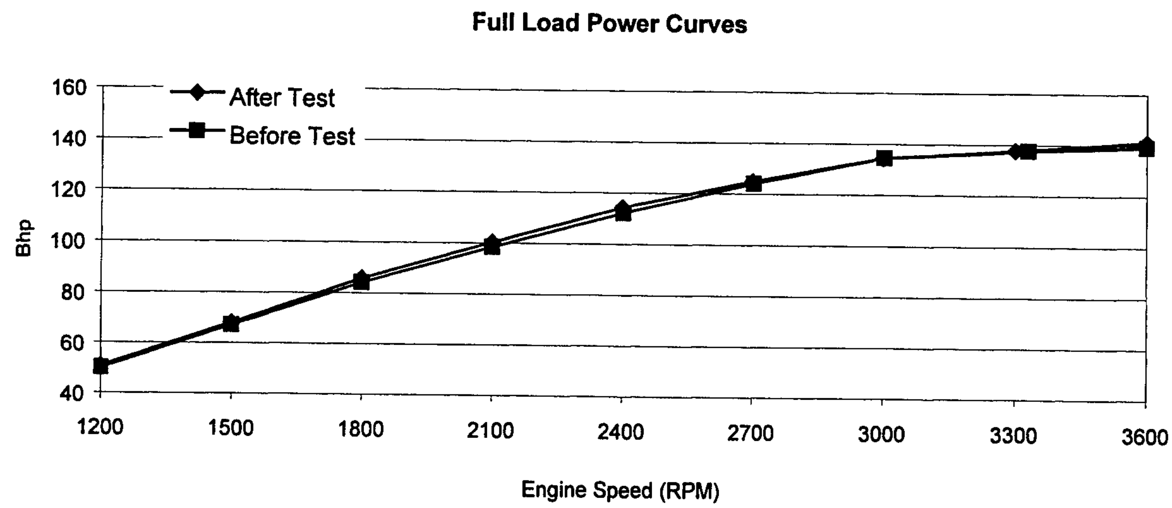


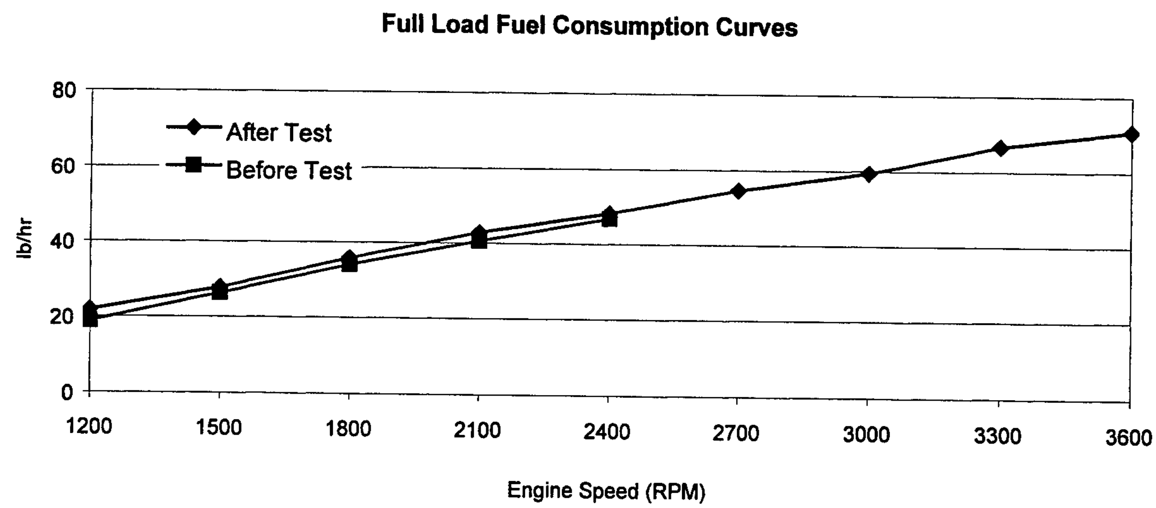
Figure 2. <u>Load Rating During Tests 97-1 and 97-2</u>

F. Results of Tests 97-1 and 97-2

1. Engine Performance

Before and after each test in the 6.2L engine, a series of performance evaluations were determined over the speed range of the engine. Curves were plotted for power, fuel consumption, and brake-specific fuel consumption over the speed range of 1200 to 3600 RPM. Based on the measurement techniques for engine speed, load, and fuel consumption, the estimated uncertainty is 1.5%. Differences greater than 1.5% should be considered meaningful. Figure 3 shows the before-and-after test, full-load performance curves for Test 97-1 that used neat JP-8. Full-load performance curves for Test 97-2, conducted using the blend of JP-8 and 7.5%v used oil are presented in Figure 4. The full-load performance curves obtained using neat JP-8 before Test 97-2 was conducted are presented in Figure 5. These curves are similar to Test 97-1 before test curves.





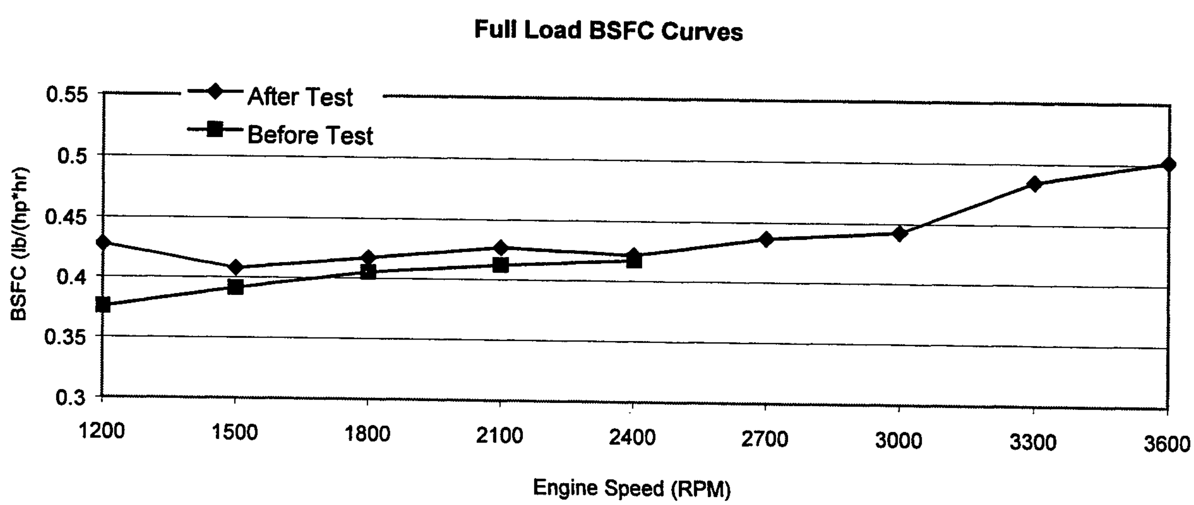
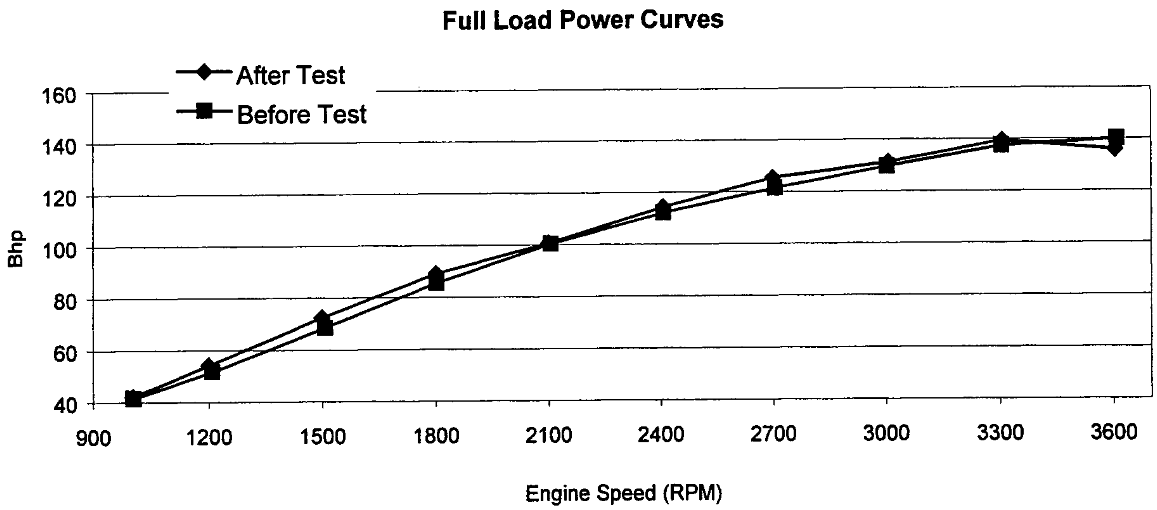
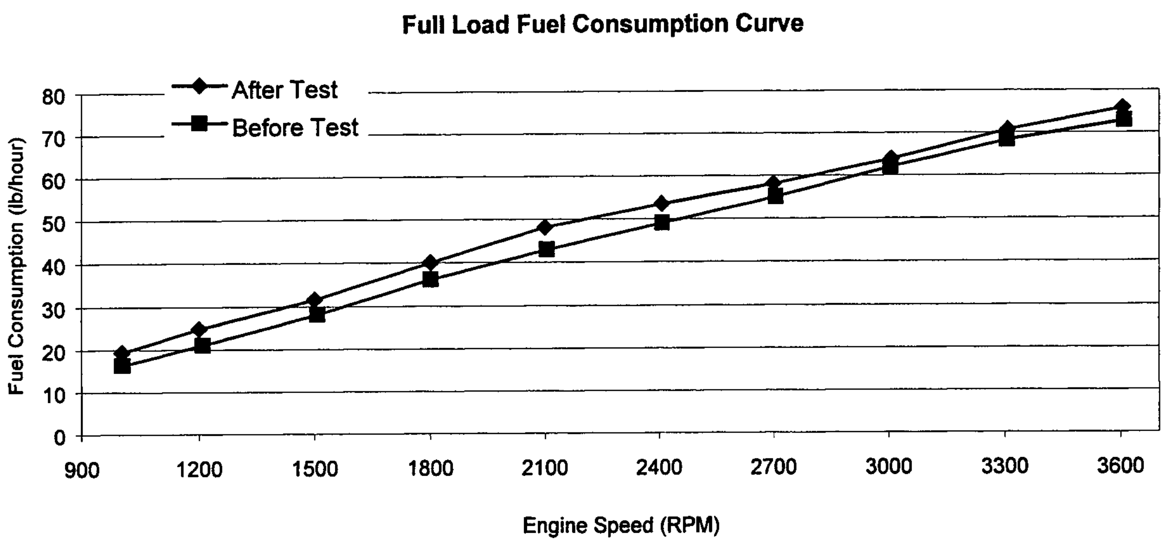


Figure 3. Before-and-after test, Full Load Performance Curves using JP-8 for Test 97-1





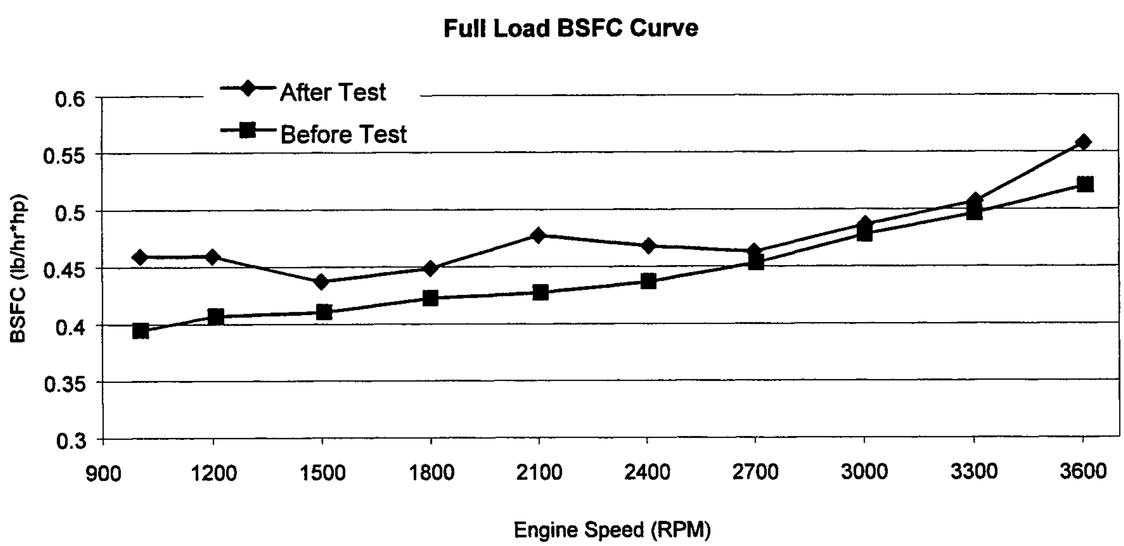
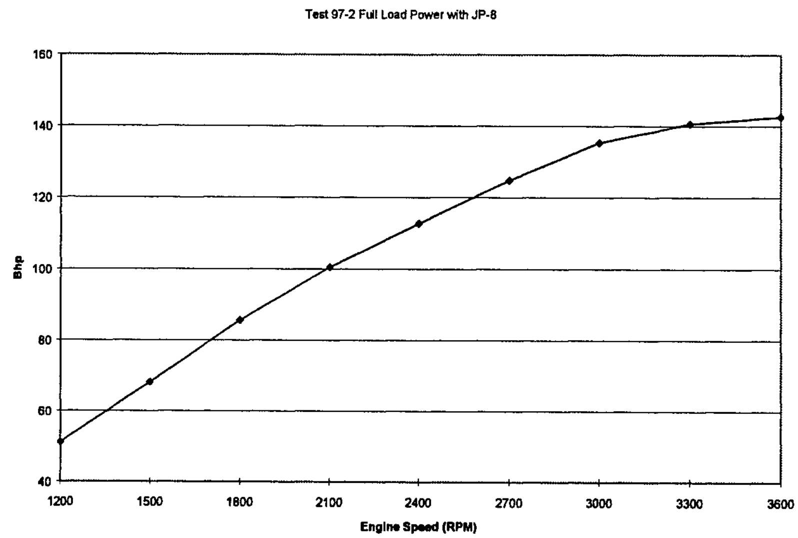
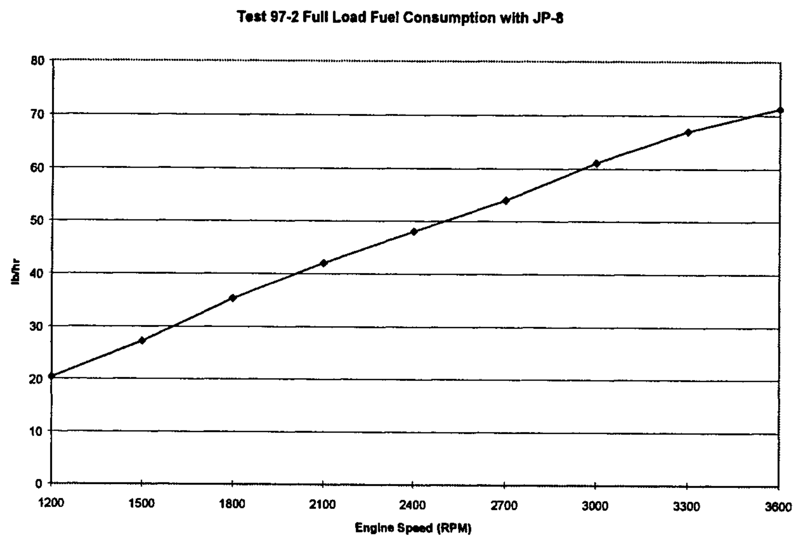


Figure 4. Full Load Performance Curves for Test 97-2





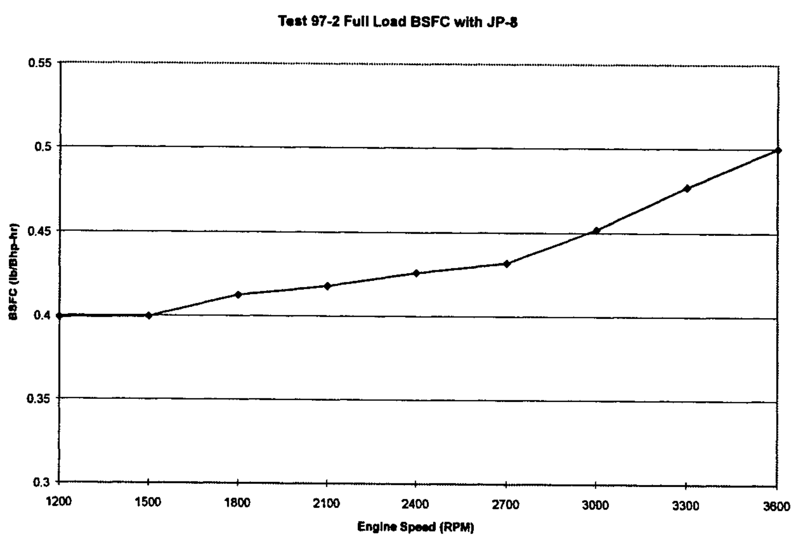
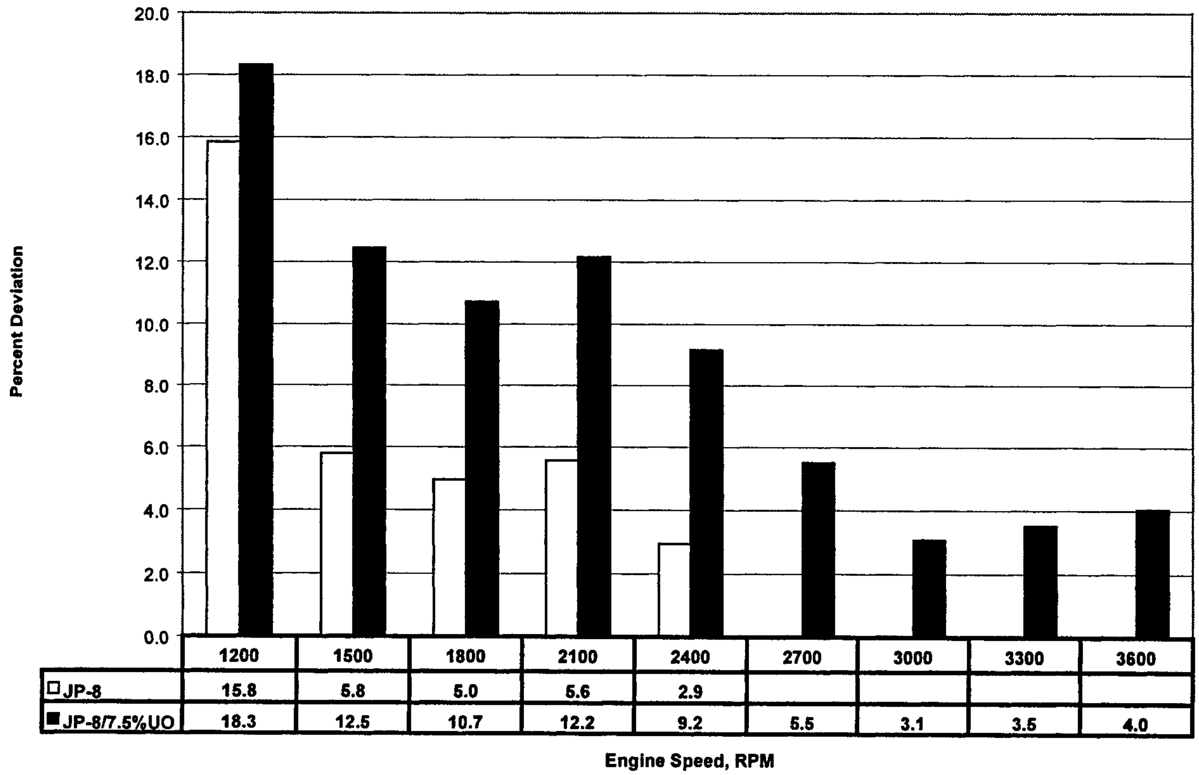


Figure 5. **Full Load Performance Curves Using JP-8 Before Test 97-2**

Comparisons were made of before-and-after test performance curves for each test. The comparison of the before-and-after engine performance curves for each fuel gives an indication of the fuels compatibility with the engine. The percent deviation for a parameter was defined as: $\frac{AfterTest - BeforeTest}{BeforeTest} \times 100$. The deviation in fuel consumption during the before and after test power curves for the JP-8 and JP-8/7.5% used oil blend are shown in Figure 6. Both fuels show an increase in fuel consumption after the 210-hour endurance cycle, which can be attributed to break-in and wear of the fuel injectors and the rotary fuel injection pumps.

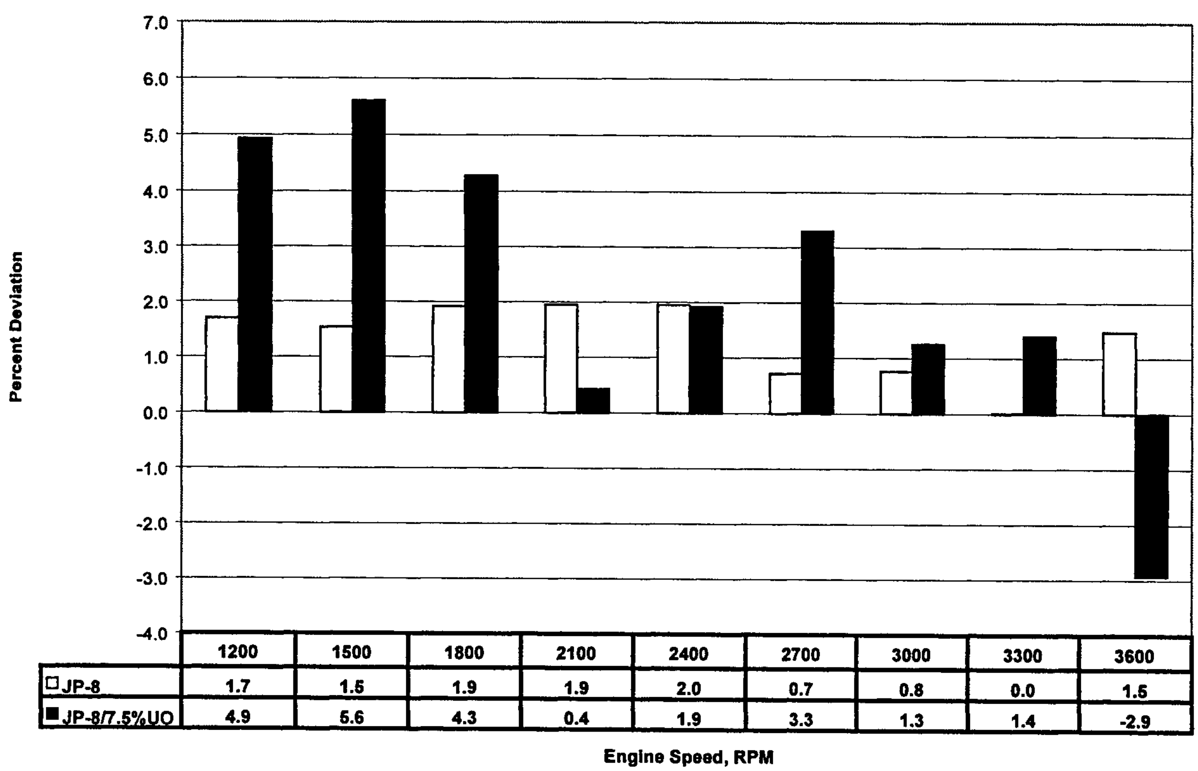
The power produced during the before and after test power curves for the JP-8 and JP-8 blend are shown in Figure 7. The power increase for the post-test curves can be partially attributed to engine run-in which typically reduces friction and the increase in fuel flow. The neat JP-8 shows a more consistent increase in post-test power at all engine speeds. The JP-8 blend shows a reduction in power production at rated engine speed after test.

The brake specific fuel consumption for the before and after test power curves for the JP-8 and JP-8 blend are shown in Figure 8. The JP-8 blend and neat JP-8 show increases in post-test BSFC across the entire engine speed range. Increases in BSFC indicate a reduction in engine efficiency, which may be due to wear in the fuel injection system that affects the fuel injection timing; however, the post-test fuel injection pump inspections revealed only minor post-test performance changes for both fuels. The heavy ash deposits seen around the pre-combustion chambers of the GM 6.2L engine after the JP-8 blend test may account for some of the BSFC increase.



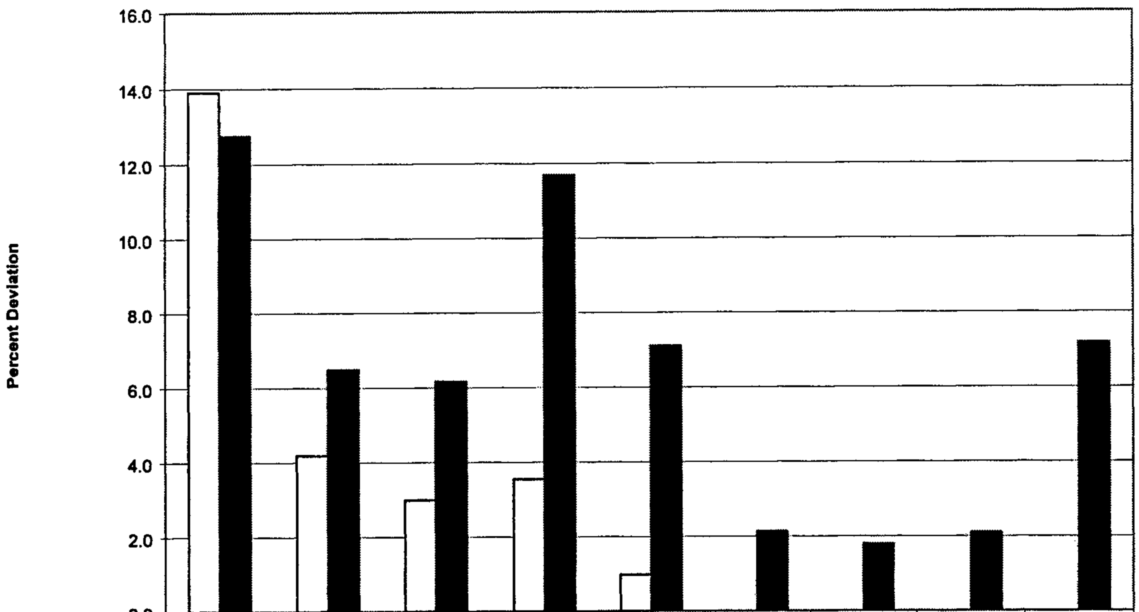
	1200	1500	1800	2100	2400	2700	3000	3300	3600
□ JP-8	15.8	5.8	5.0	5.6	2.9				
■ JP-8/7.5%UO	18.3	12.5	10.7	12.2	9.2	5.5	3.1	3.5	4.0

Figure 6. Comparison of Fuel Flow (lb/hr) After Test to Before Test



	1200	1500	1800	2100	2400	2700	3000	3300	3600
□ JP-8	1.7	1.5	1.9	1.9	2.0	0.7	0.8	0.0	1.5
■ JP-8/7.5%UO	4.9	5.6	4.3	0.4	1.9	3.3	1.3	1.4	-2.9

Figure 7. Comparison of Power (bhp) After Test to Before Test

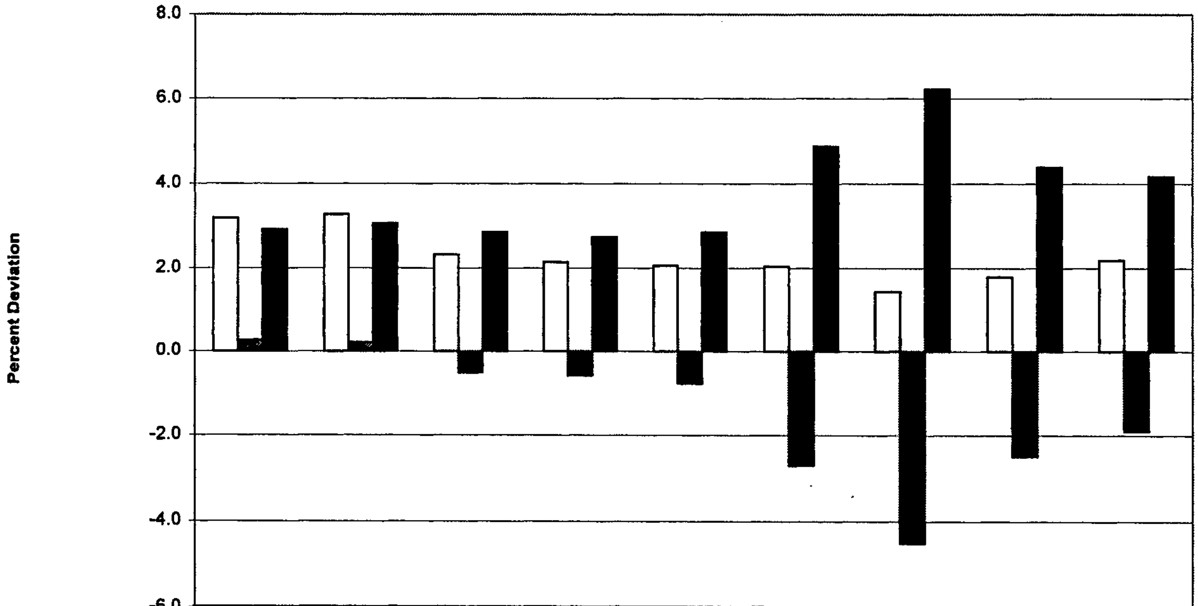


	1200	1500	1800	2100	2400	2700	3000	3300	3600
□ JP-8	13.9	4.2	3.0	3.5	1.0				
■ JP-8/7.5%UO	12.8	6.5	6.2	11.7	7.1	2.1	1.8	2.1	7.2

Engine Speed, RPM

Figure 8. Comparison of BSFC (lb/bhp-hr) After Test to Before Test

Performance comparisons of JP-8 and JP-8 blended with 7.5% used oil were made prior to the start of Test 97-2. This provided comparisons between fuels on the same engine build. The deviations of fuel flow, power and brake specific fuel consumption (BSFC) between JP-8 and the JP-8 blend are shown in Figure 9. The engine appeared to have higher fuel consumption with JP-8 blend across the entire speed range. Except for improvements in power at the lowest speeds with the JP-8 blend, neat JP-8 produced slightly more power in the GM 6.2L engine. Some of the variations in fuel consumption are due to the viscosity and density deviation of the JP-8 and JP-8 blend. The BFSC represents the efficiency of the fuel conversion to power. The data suggest the GM 6.2L engine conversion of the JP-8 blend fuel energy to power is slightly less efficient than neat JP-8.



	1200	1500	1800	2100	2400	2700	3000	3300	3600
□ fuel flow, lb/hr	3.2	3.3	2.3	2.1	2.1	2.0	1.4	1.8	2.2
■ power, bhp	0.3	0.2	-0.5	-0.6	-0.8	-2.7	-4.5	-2.5	-1.9
■ bsfc, lb/bhp-hr	2.9	3.1	2.9	2.7	2.9	4.9	6.2	4.4	4.2

Engine Speed, RPM

Figure 9. Deviations From JP-8/7.5%UO to JP-8 Before Test Power Curve, Test 97-2

Full load performance comparisons were made between Test 97-1 (JP-8) and Test 97-2 (Blended fuel). The comparisons were for:

1. Before-test performance ((Test 97-1 versus Test 97-2)
2. After-test performance (Test 97-1 versus Test 97-2)

It should be noted that variations between the two tests can be attributed to two factors: differences in the fuel properties and slight variations in engine build-up measurements. Figure 10 shows the difference in maximum power developed, as the percent change of the test run on blended fuel from the baseline neat fuel test. According to this figure, the 6.2L engine achieved somewhat higher maximum power at low speeds when fueled by the JP-8/used oil blend, but it achieved lower maximum power at high speeds when fueled by the blend.

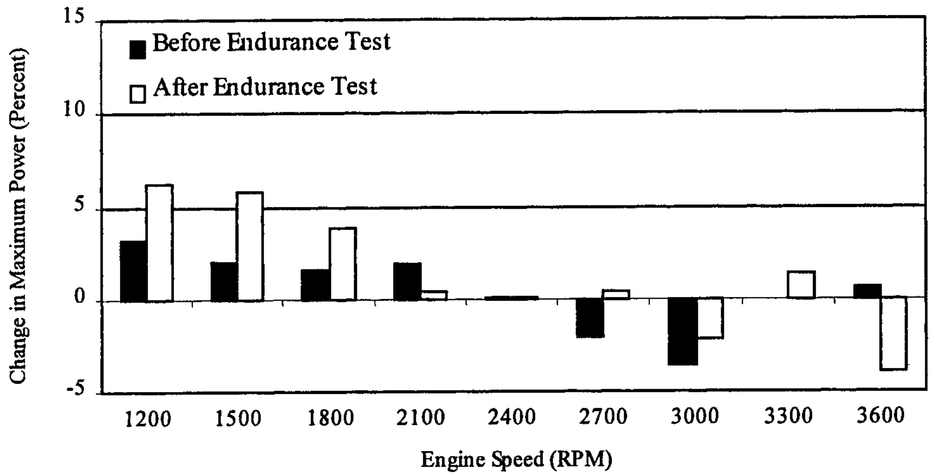


Figure 10. Change in Maximum Power from Test 97-1 to Test 97-2

The increase in power at low speeds is related to the large increase in fuel consumption, as shown in Figure 11 (fuel flow data for part of the power curve done before test 97-1 is not available). Some increase in fuel flow can be attributed to the increased viscosity and fuel density of the blended fuel. Additionally, Figure 11 shows that the increase in fuel consumption was greater during the power curve that was generated after the tests than during the power curve before the tests.

In Figure 12, the difference in Brake Specific Fuel Consumption (BSFC) from Test 97-1 to 97-2 is shown. Over the entire range of engine speeds, there was a large increase in BSFC when the engine was operated on blended fuel. For end-of-test comparison, this could be a result of the large amounts of ashy deposits that were found after Test 97-2 on exit of the pre-combustion chamber into the main combustion chamber. It is suspected that these deposits disrupted the airflow to the swirl chamber, reducing mixing and the efficiency of the engine. BSFC is a function of how effectively fuel is converted to power. It is evident that the engine was operating less efficiently on blended fuel both before and after the test. Even in the low-speed range, where maximum power was higher using blended fuel, the fuel flow increase was large enough that BSFC increased significantly.

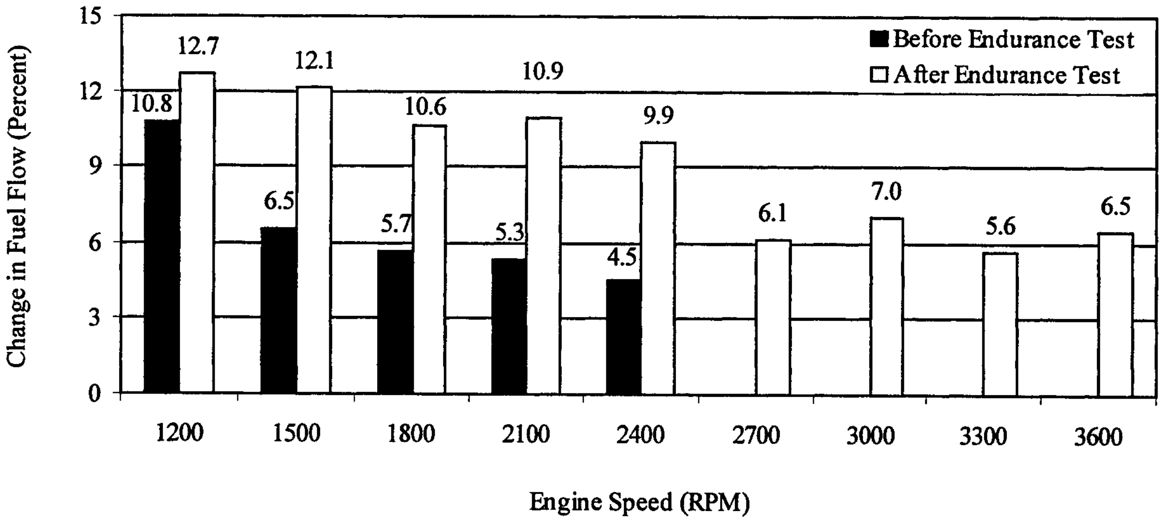


Figure 11. Change in Fuel Flow from Test 97-1 to 97-2

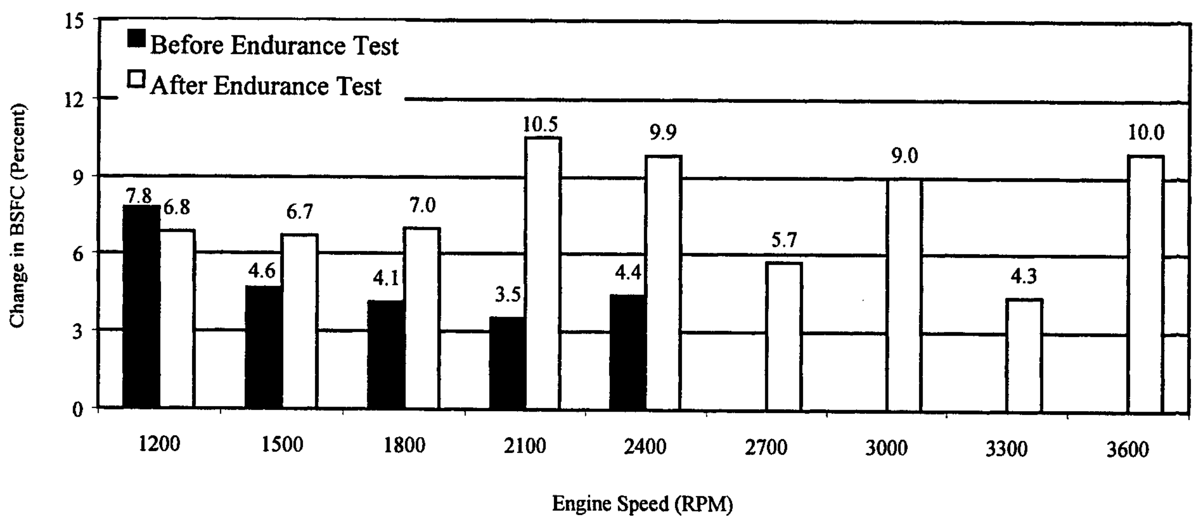


Figure 12. Change in BSFC from Test 97-1 to 97-2

2. Engine Durability

The effects that the different fuels had on the durability of the engine can be determined through comparisons of the deposits and wear that were found upon disassembly of the engine after the tests. In Section IV-D, the inadvertent use of over-sized exhaust valves during Test 97-1 was discussed. The use of these over-sized valves caused some of the pushrods to bend when the valves contacted the piston crowns. Additionally, it caused unusual amounts of wear in some areas such as cylinders and valve guides. Therefore,

when wear on these components is discussed, results from Tests 97-1 an 97-2 will also be presented with more typical results that were obtained during a previous program. That program utilized a GM 6.2L engine, fueled with a different neat JP-8 and lubricated with a different oil (REO-203, SAE 30-grade).

The blend of used oil in the JP-8 fuel had a significant effect on deposits in the precombustion chamber. After Test 97-2, unusual ash deposits were found at the exit of the pre-chamber combustion area into the main combustion chamber. These deposits were probably the result of the increased amount of soot, wear metals, ash and fuel residuals that the used oil brings to the fuel. The distillation of the test fuels shows a 6.1% residue with the oil blend versus only 1% residue for neat JP-8. Figure 13 illustrates some of these deposits.

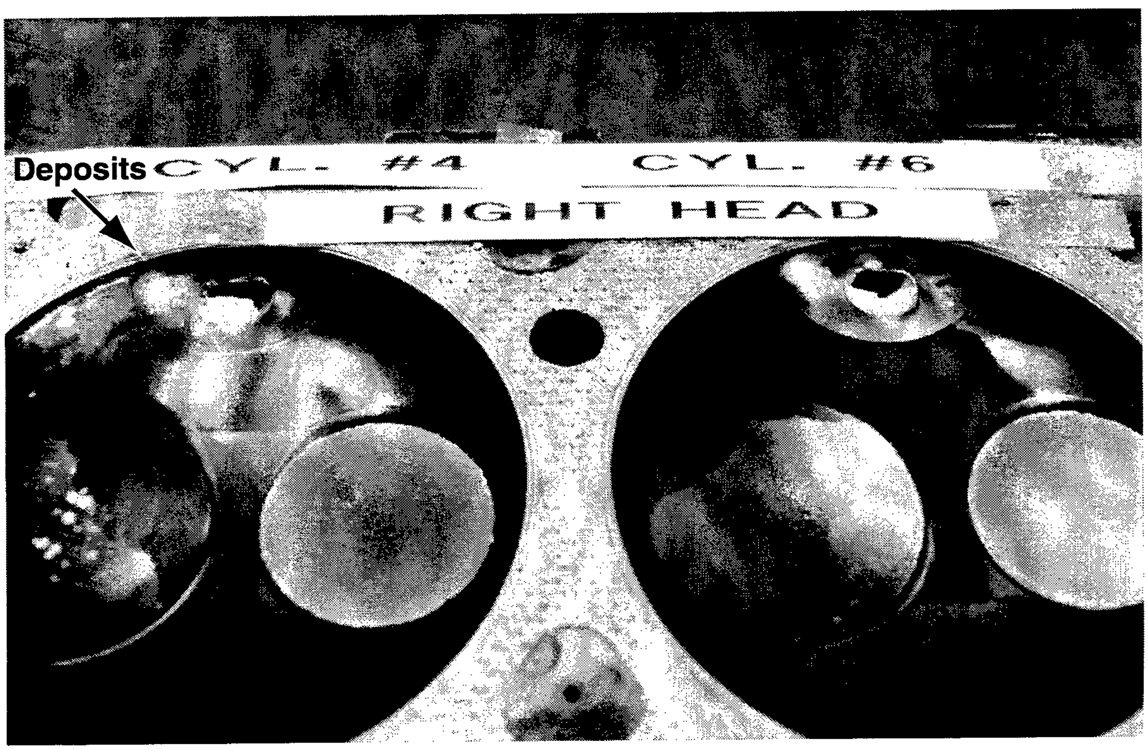


Figure 13. Deposits at Pre-Combustion Chamber Exit, Test 97-2

Engine deposit ratings were determined by a trained rater using standard CRC Deposit Rating methods. For merit ratings, 10 equals clean; for demerit ratings, ∅ equals clean. Engine deposits in areas other than the prechamber exits were not significantly affected by the addition of used oil to the fuel. As can be seen in Figures 14-17, piston weighted total deposits (WTD), intake and exhaust valve deposits, main combustion chamber deposits, and piston top groove fill were all approximately the same for the neat JP-8 and the blended fuel.

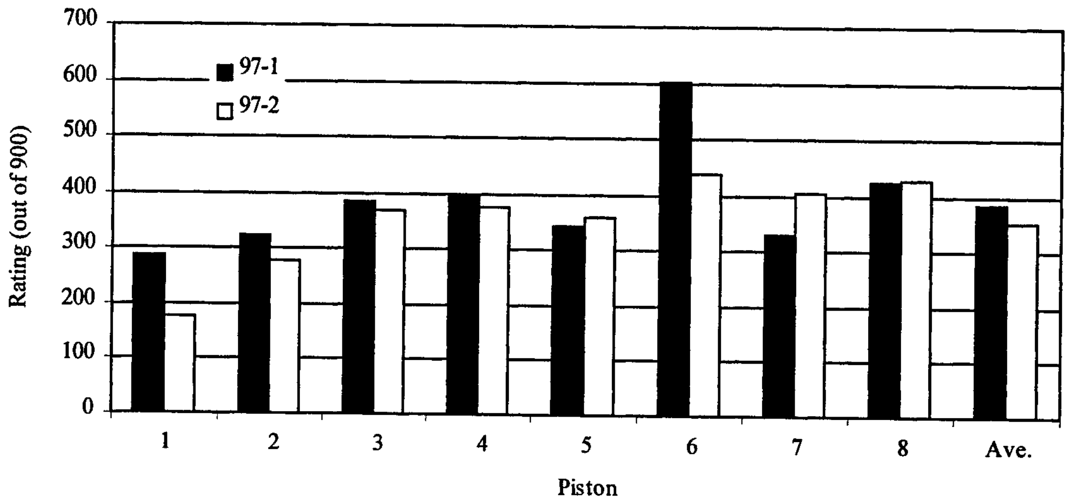


Figure 14. Piston-Weighted Total Deposits (Demerits), Tests 97-1and 97-2

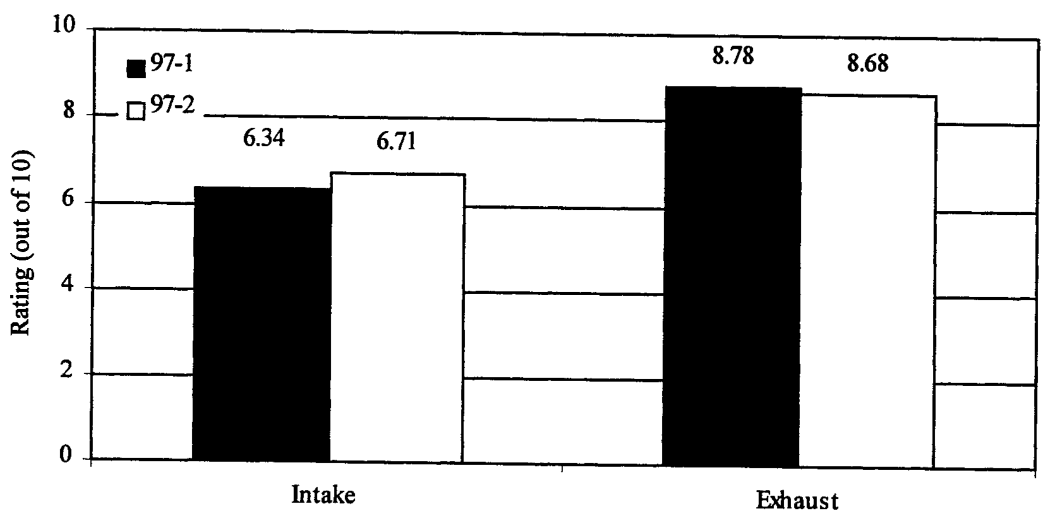


Figure 15. Valve Deposits (Merits), Tests 97-1 and 97-2

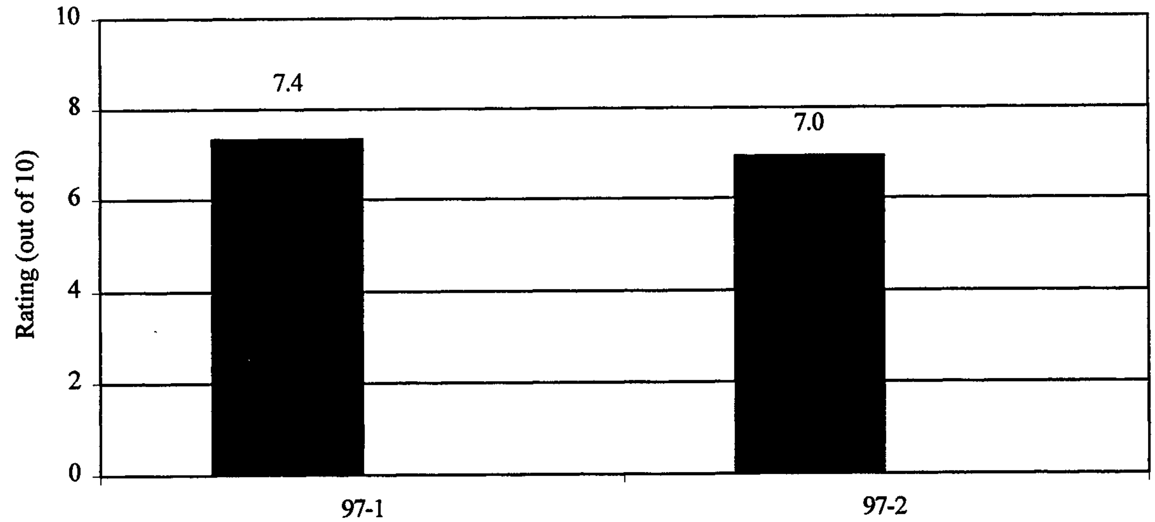


Figure 16. Combustion Chamber Deposits (Merits), Tests 97-1 and 97-2

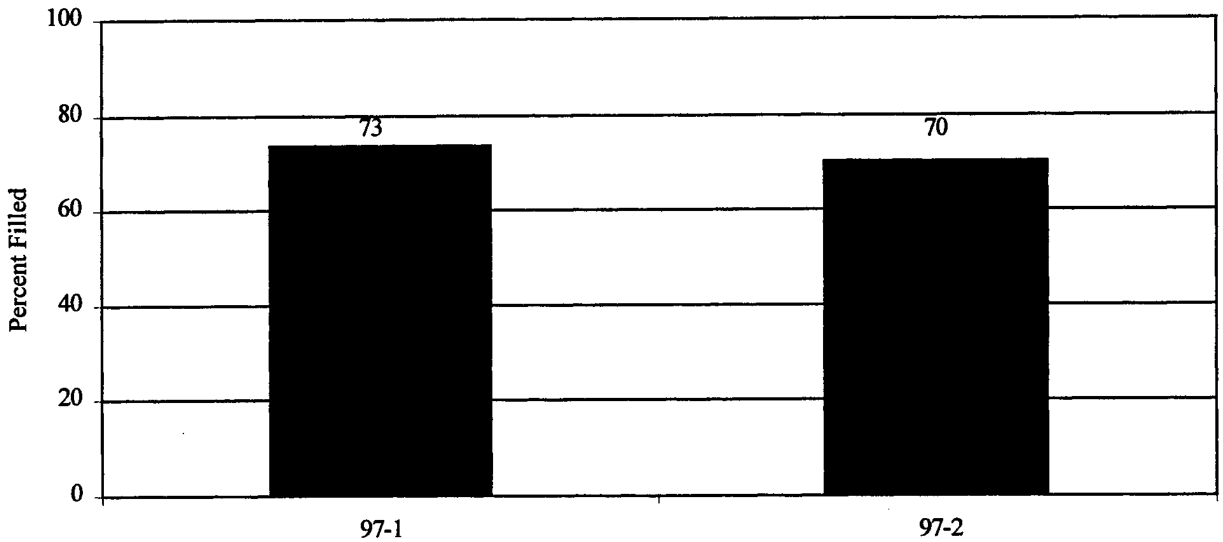


Figure 17. Piston Top Groove Fill, Tests 97-1 and 97-2

Although the weight loss of the rod bearings didn't change from the "typical" test to Test 97-2, the weight loss of the main bearings increased substantially (Figure 18). This may be attributed to the abrasion caused by increased amounts of wear metals and ash in the JP-8 blended with used oil that was carried into the engine crankcase oil via blow-by.

Cylinder bore wear decreased slightly when the blended fuel was used, compared to the typical wear shown in Figure 19. Bore scuffing was the same for Test 97-2 as it was for the typical test; both tests had almost no bore scuffing (Figure 20). However, some

increase in piston ring end gap change (wear) was found for Test 97-2 (Figure 21) when compared to the "typical" results. These results seem somewhat contradictory. The increase in ring wear could be attributed to the less volatile components and ash in the blended fuel which may not burn as cleanly as the JP-8, and results in more solids passing the rings in the engine blow-by. It is not clear why the rings experienced slightly higher wear while the bore experienced slightly lower wear. The cylinders see a contact condition four times per cycle, while the rings are always loaded. There are wear mechanisms where an abrasive particle can embed in a softer material and subsequently cause wear in the harder material that is in contact with the particle.

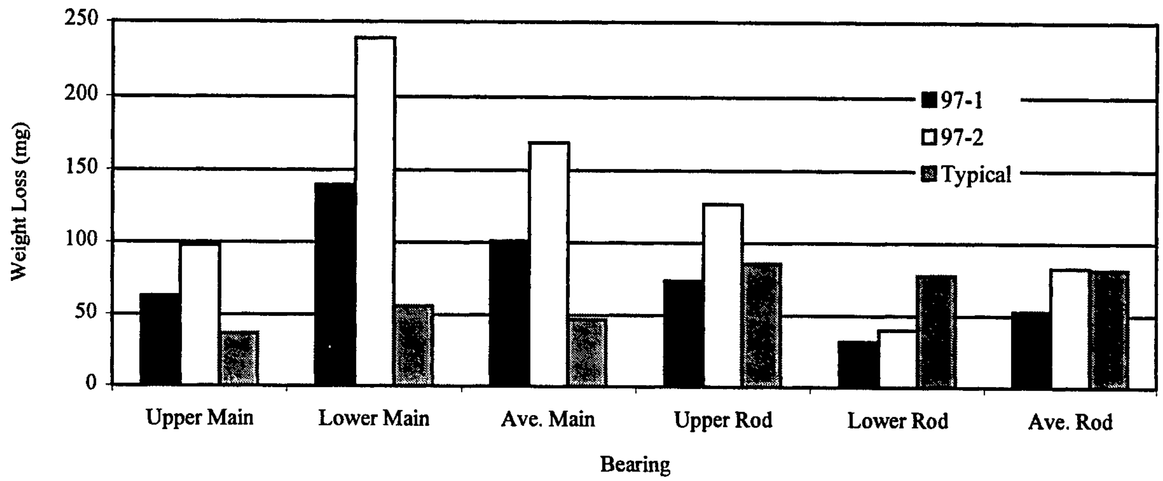


Figure 18. Bearing Weight Loss, Tests 97-1, 97-2 and Typical

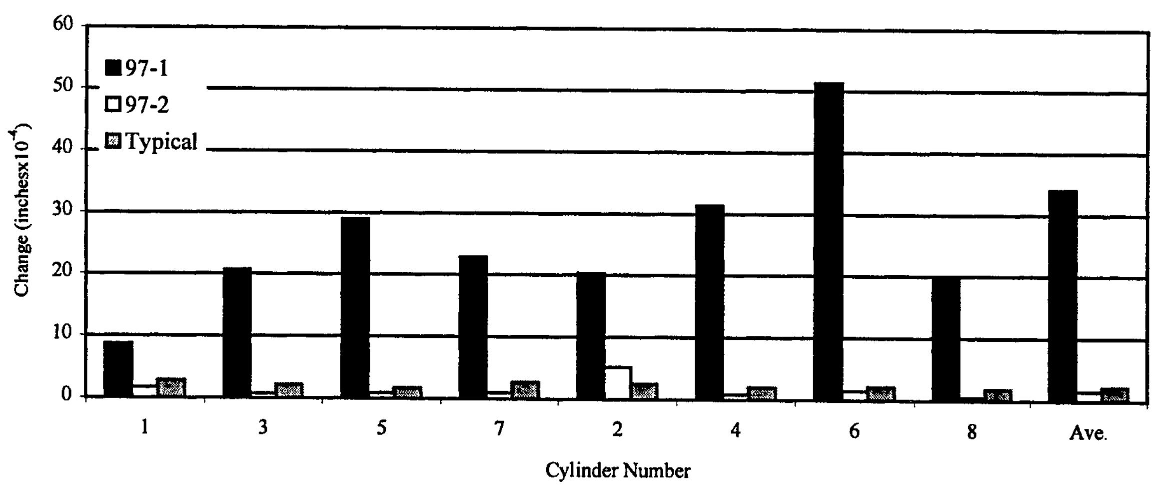


Figure 19. Cylinder Bore Diameter Change, Tests 97-1, 97-2 and Typical

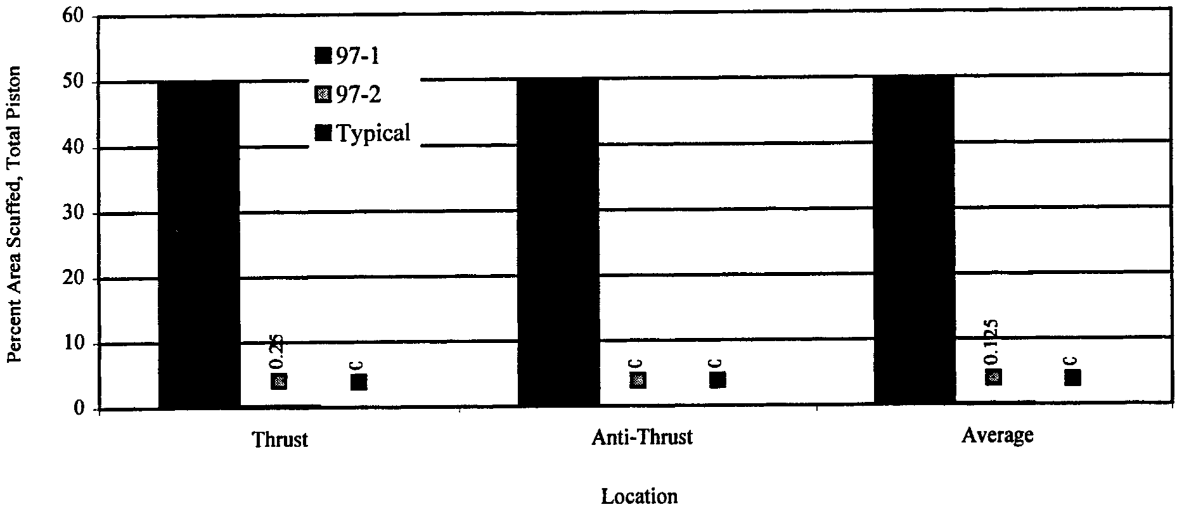


Figure 20. Cylinder Bore Scuffing, Tests 97-1, 97-2, Typical

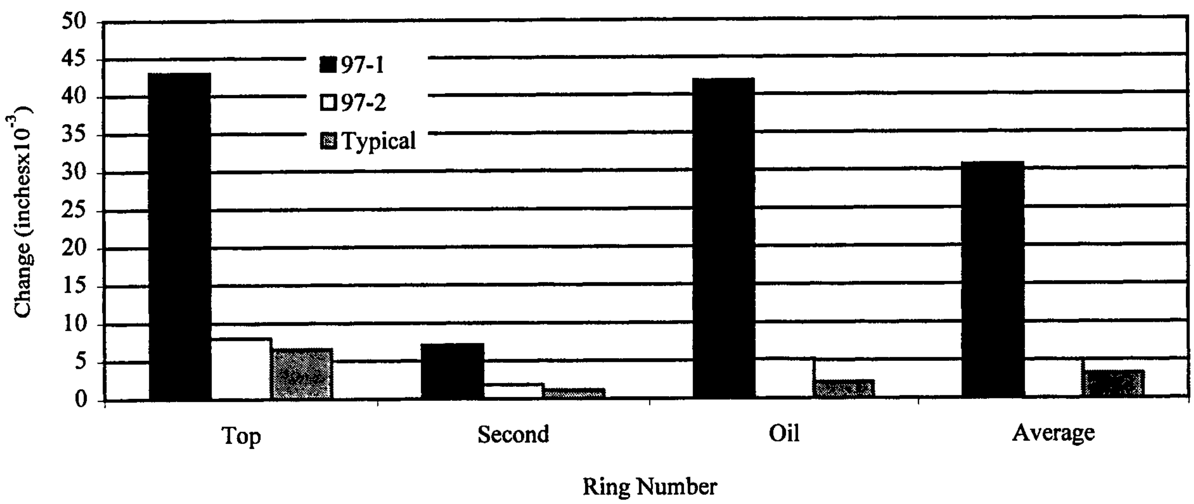


Figure 21. Piston Ring End Gap Change, Tests 97-1, 97-2 and Typical

3. Lubricant Analysis

Throughout both tests, the engine crankcase oil was periodically tested to determine viscosity, total acid and total base numbers, and wear metal content. Wear metal content in the oil (iron, copper, and lead) was higher at the end of Test 97-2 than at the end of Test 97-1. However, before the oil change at 154 hours, the content of iron and lead was much higher for Test 97-1 than Test 97-2, as shown in Figure 22. The problem of

oversized exhaust valves contributed to the higher wear metals in Test 97-1. There was more copper present in the engine oil of Test 97-2 at the oil change and at the end of the test. This correlates with the increase in the wear of the main bearing during Test 97-2.

Total Acid Number (TAN) increases and Total Base Number (TBN) decreases for the two tests were similar. Additionally, the lubricant for the blended-fuel test experienced slightly less viscosity increase than the lubricant for the neat fuel test. Plots of TAN, TBN, viscosities and wear metals versus test hours are presented in Appendices A and B. Based on analysis of the engine crankcase oil, the addition of the used oil to JP-8 fuel did not have a major impact on used crankcase oil properties.

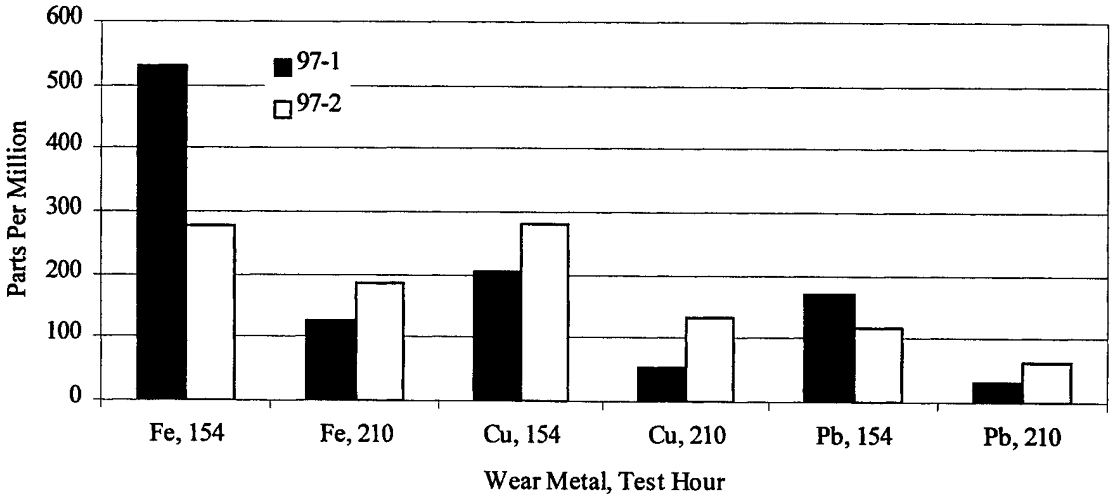


Figure 22. Lubricant Wear Metal Content Before Oil Change and at End of Test, Tests 97-1 and 97-2

4. Fuel Injection System

The fuel injectors were tested before and after each test. Pop-off pressure, or cracking pressure, remained well above specification limits during both the baseline and experimental tests. No change in the quality of the spray pattern was observed. A visual inspection did find that after Test 97-2, two of the fuel injector nozzle tips were unusually discolored (injectors 2 and 5), as if they had been extremely hot at some time during the test. Leak back time did not change after the baseline JP-8 test. Leak back time for all

but three of the injector nozzles fell below the minimum specification limits at the end of Test 97-2. The discolored nozzle tips failed the leak back time, but so did nondiscolored ones. In addition, the amount of returned fuel had increased by the end of Test 97-2. These factors could result in increased leakage within the pump, and less efficient operation of the engine. This is in agreement with the increase in fuel flow and BSFC shown earlier in Figures 11 and 12. The calibration of the fuel pump changed little from the beginning to end of either test, and the housing pressure within the pump did not change.

V. DD 6V-53T ENGINE ENDURANCE TESTS

A. Engine Description

A description of the DD 6V-53T engine is presented in Table 9, and a photograph of the engine dynamometer installation is shown in Figure 23. The two-cycle diesel engine family is widely used in U.S. Army combat and tactical equipment, as shown in Table 10.

Table 9. DD 6V-53T Engine Specifications	
Model:	5063-5395
Engine Type:	Two Cycle, Compression Ignition, Direct Injection, Turbo-Supercharged
Cylinders:	6, V-Configuration
Displacement, L (in.^{3}):	5.21 (318)
Bore x Stroke, mm (in.):	9.8 x 11.4 (3.875 x 4.5)
Compression Ratio:	18.7:1
Rated Power, kW (BHP):	224 (300) at 2800 RPM
Rated Torque, Nm (ft-lb):	858 (633) at 2200 RPM
Injection System:	DD Unit Injectors, N-70

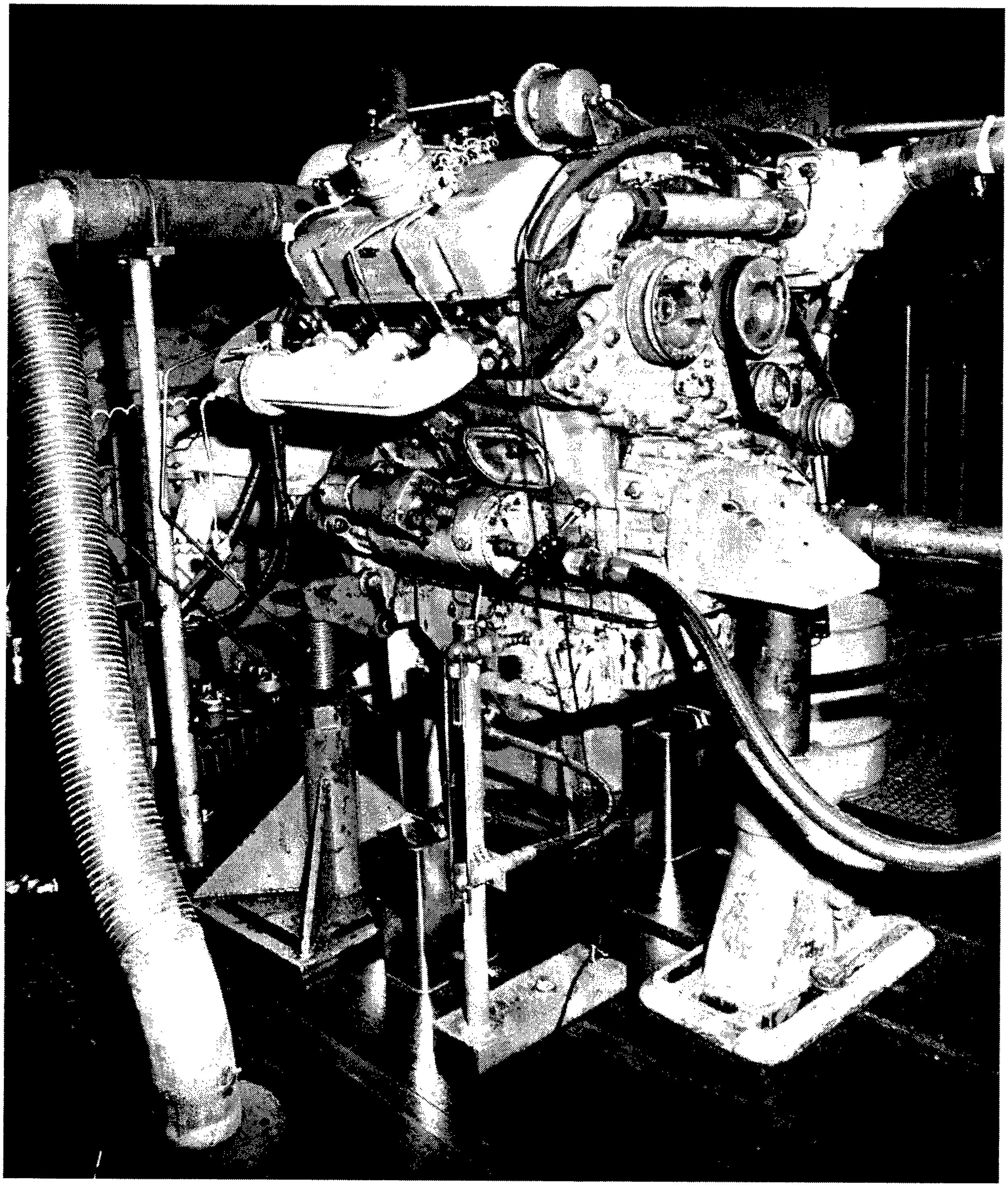


Figure 23. <u>Installation of DD 6V-53T Engine</u>

Table 10. Army Combat/Tactical Vehicles Powered by DDC Two-Cycle Engines		
Designation	**Description**	**Engine Model**
M106A1, A2	Mortar, Self-Propelled (SP), 107 mm	6V-53
M107	Gun, Self-Propelled, 175 mm	8V-71T
M108	Howitzer, Self-Propelled, 105 mm	8V-71T
M109A1, A2, A3	Howitzer, Medium, 155 mm	8V-71T
M110A1, A2	Howitzer, Self-Propelled, 8 inch	8V-71T
M42A1	Gun, Anti-Aircraft, SP	6V-53
M163A1	Gun, Air Defense, SP	6V-53
M113A1, A2	Carrier, Guided Missile, TOW; Personnel, Full-Tracked (FT)	6V-53
M113A1 (Stretch)	Carrier, Personnel, Stretched, FT, Armored	6V-53T
M113A2E1	Carrier, Personnel, FT, Armored	6V-53T
M125A1, A2	Mortar, Self-Propelled, FT	6V-53
M132A1	Flame Thrower, Self-Propelled	6V-53
M116	Carrier, Cargo, Amphibious	6V-53
M548	Carrier, Cargo, Tracked	6V-53
M548 (Stretch)	Carrier, Cargo, Tracked, Stretched	6V-53T
M551	Armored Reconnaissance/Airborne Assault Vehicle (Sheridan)	6V-53T
M561	Truck, Cargo, 1¼ T (Gamma Goat)	3-53
M792	Truck, Ambulance, 1¼ T	3-53
M577A1, A2	Carrier, Command Post, Light-Tracked	6V-53T
M578	Recovery Vehicle, FT, SP	8V-71T
M992, XM1050	Field Artillery Ammunition Support Vehicle (FAASV), FT, SP	8V-71T
M752, M688E1	Carrier, Loader/Launcher/Transporter (Lance)	6V-53
M667	Carrier, Guided Missile (Lance), Equipment, SP, FT	6V-53
XM727	Carrier, Guided Missile, Equipment, SP, FT	6V-53
M730, A1	Carrier, Guided Missile (Chaparral), SP, FT	6V-53
M730, A2	Carrier, Guided Missile (Chaparral), SP, FT	6V-53T
M741, A1	Chassis, Gun, AA (VULCAN), 20 mm, SP, FT	6V-53
M806E1	Recovery Vehicle, FT, Armored	6V-53
M901, A1	Improved TOW Vehicle Carrier, FT	6V-53
M981	Fire-Support Team Vehicle, FT, SP	6V-53
M1015, A1	Carrier, Electronic Shelter, FT, SP	6V-53
M1059	Carrier, Smoke Generator, FT, SP	6V-53
M113A1, A2	Fitters Vehicle, FT, SP	6V-53
M878, A1	Truck, Tractor, 5 T, Yard Type	6V-53T
M911	Truck, Tractor, Heavy Equipment Transporter	8V-92TA
M746	Truck, Tractor, Heavy Equipment Transporter	12V-71T
M977, 978, 985	Truck, Cargo, Tactical, 8x8 HEMTT	8V-92TA
M978	Truck, Tank, FT, 2500 gal.	8V-92TA
M983	Truck, Tractor, Tactical, 10T, HEMTT	8V-92TA
M984,A1	Truck, Wrecker, Tactical	8V-92TA
M1070	Truck, Tractor, HET	8V-92TA
M1074,M1075	Truck Cargo, Hy PIS	8V-92TA
M915A2	Truck Tractor, Line Haul	8V-92TA

B. Test Cycle

The engine test cycle used in this portion of the program was a modified version of FTM 791C, Method 355 (5), shown in Table 11. The modification was the use of blended fuel. This cycle has been correlated to 6,437 km (4,000 mi) of proving ground experience. (3)

Table 11. Army/CRC 240-Hour Tracked-Vehicle Endurance Cycle (FTM Method 355)		
Period*	**Time, hr**	**Rack/Throttle Setting**
1	0.5	Idle
	2.0	Maximum Power
	0.5	Idle
	2.0	Maximum Torque
2	0.5	Idle
	2.0	Maximum Power
	0.5	Idle
	2.0	Maximum Torque
3	0.5	Idle
	2.0	Maximum Power
	0.5	Idle
	2.0	Maximum Torque
4	0.5	Idle
	2.0	Maximum Power
	0.5	Idle
	2.0	Maximum Torque
5	4	5 min. idle, followed by shutdown
* These five periods yield 20 hours of running with a 4-hour shutdown; this cycle is repeated 12 times for a total test time of 240 hours.		

C. Lubricant

The lubricant used in the DD 6V-53T engine tests was the CRC reference engine oil REO-203, an SAE 30 grade lubricant. When batches of this oil were received at TFLRF, they were designated as AL-12634-L and AL-24867-L, and AL-20241-L. A listing of the oil properties and composition is given in Table 12.

Table 12. DD 6V-53T Test Lubricant Properties			
Sample ID Code		**AL-12634-L**	**AL-24867-L/ AL-20241-L**
		Test 39	**Test 60**
Property	**ASTM Method**		
K. Vis, 40°C, cSt	D 445	102.9	103.31
K. Vis, 100°C, cSt	D 445	11.66	11.81
Total Acid Number	D 664	2.71	2.68
Total Base Number	D 664	5.32	4.85

D. Test 39, Neat JP-8, Baseline

The 240-hour baseline test using neat JP-8 was completed in March 1984. The test was conducted to evaluate the feasibility of replacing No. 2 diesel fuel with JP-8. Results were reported in a TFLRF Interim Report.(6) There were no unusual problems during the 240-hour tracked vehicle cycle. Detailed information and test data are presented in Appendix C.

E. Test 60, JP-8 + 7.5% vol. Used Oil

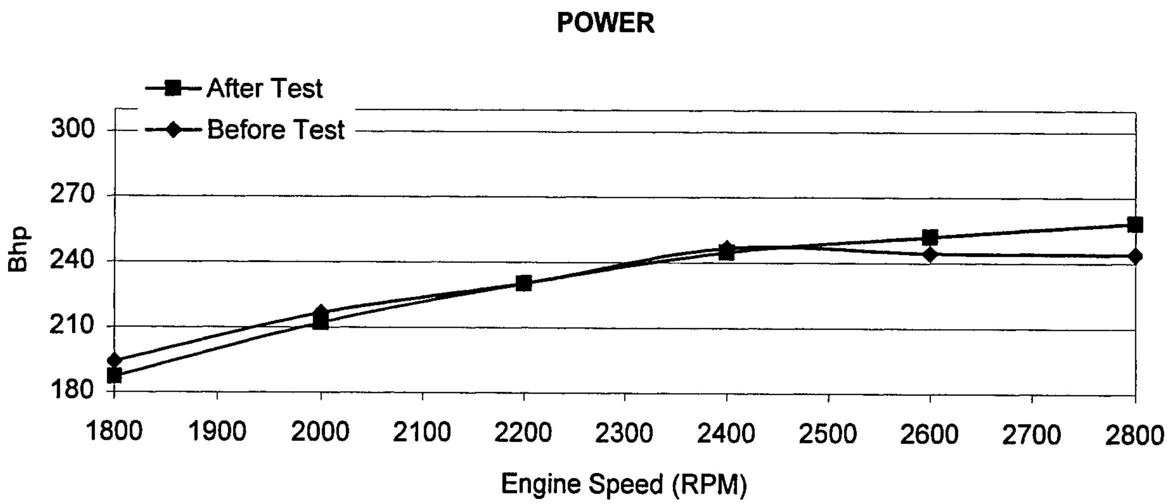
The 240-hour test using JP-8 blended with 7.5% vol. used oil on a DD 6V-53T engine was completed on 29 May 1997. Although the engine for the baseline Test 39 was not used for the test, it was the same model. The only operational problem during that 240-hour cycle was a stuck fuel injector at 53 hours. The fuel injector was replaced, and the test continued. Disassembly and inspection of the failed fuel injector revealed the failure was an isolated incident and unrelated to the test. Detailed information and test data are presented in Appendix D.

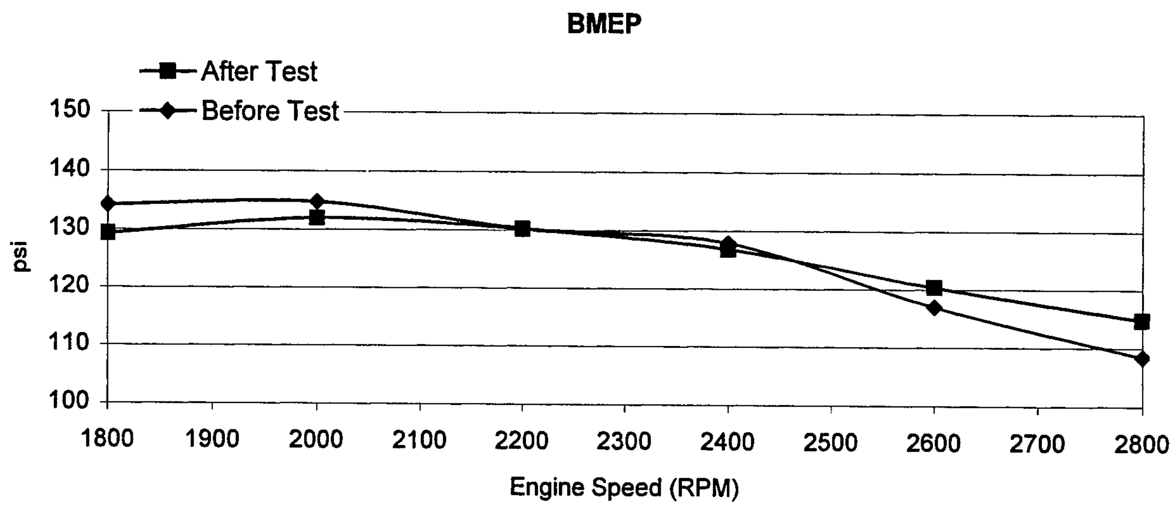
F. Results of Tests 39 and 60

1. Engine Performance

Based on the measurement techniques for engine, speed, load, and fuel consumption, the estimated uncertainty is 1.5%. Differences greater than 1.5% should be considered meaningful. Test 39 followed the FTM 355 procedure of limiting fuel flow to 120 lb/hr maximum and requiring the engine to produce a minimum, 295-brake horsepower at 2800-RPM while operating on No. 2 diesel fuel. This procedure was meant to verify engine-build quality prior to testing. The fuel flow limit is set by a governor adjustment with the engine operating on diesel fuel. The engine was switched to JP-8 fuel for Test 39 with no further governor or injector adjustments. Before-and-after test, full-load performance curves are shown in Figure 24.

Test 60 was performed without making the fuel flow limiting governor adjustments with diesel fuel. The governor cut-in and idle speeds were set using only JP-8. Fuel flow limiting adjustments at rated speed were not performed for Test 60. Before-and-after test, full-load performance curves are presented in Figure 25.





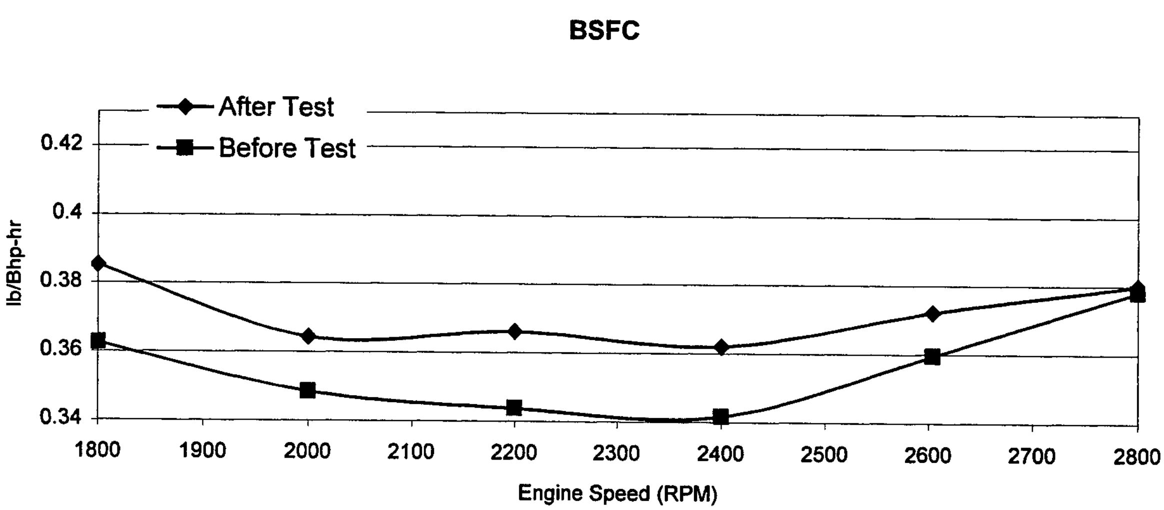


Figure 24. **6V-53T Test 39 for Power, BMEP, and BSFC**

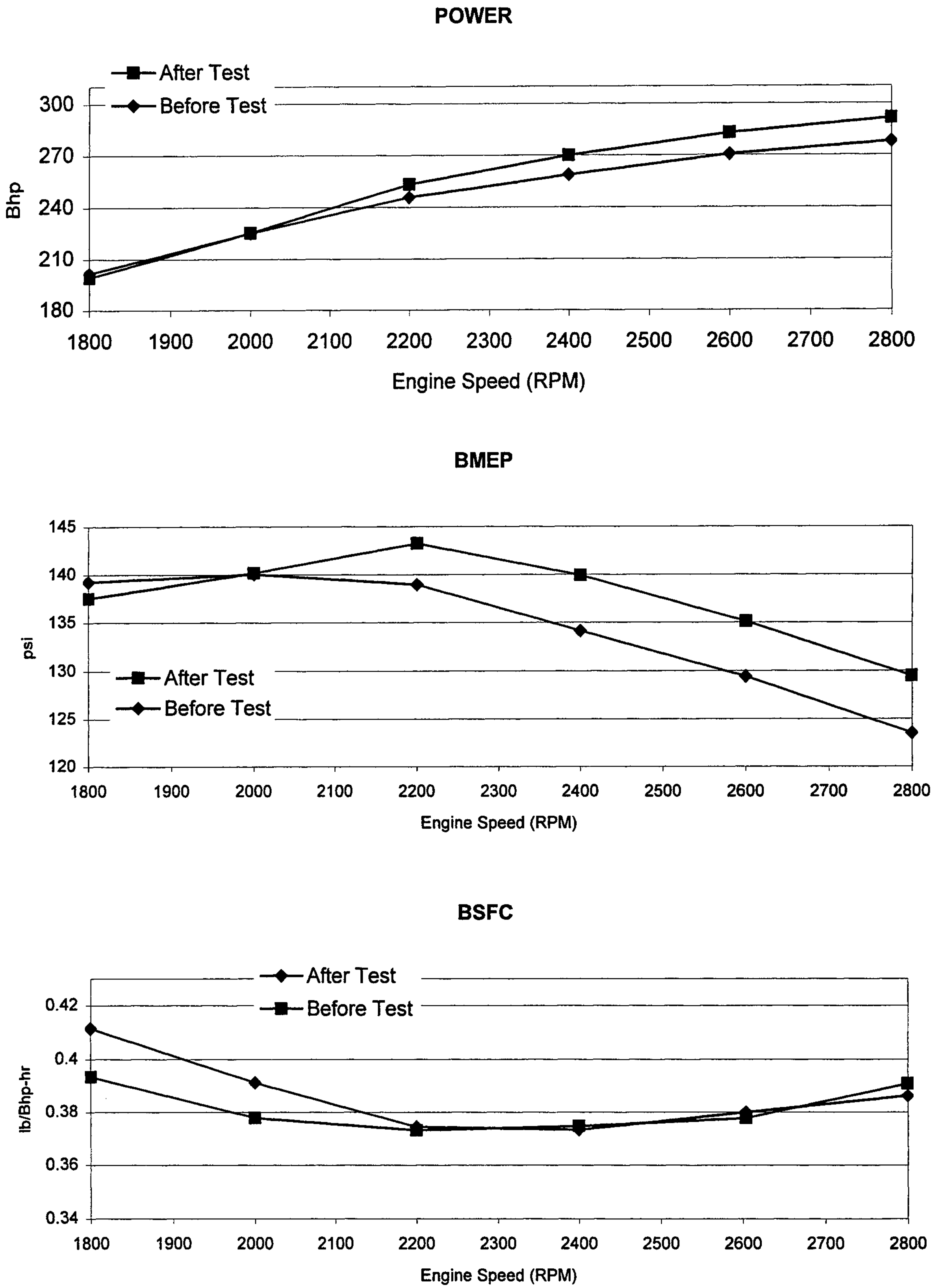


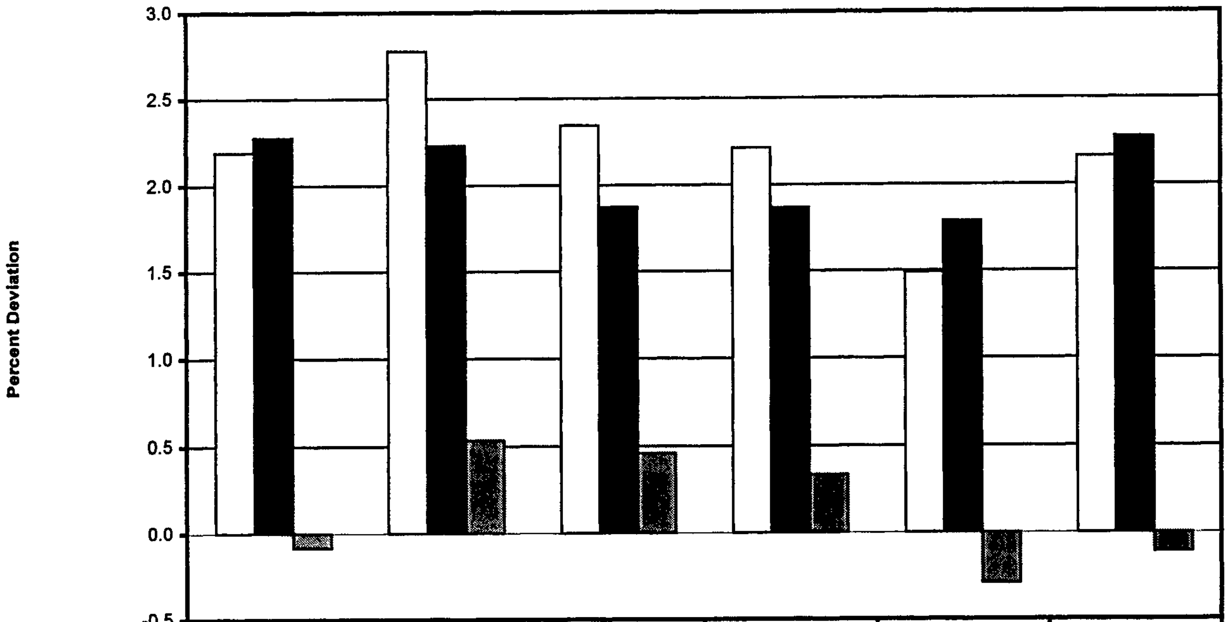
Figure 25. **6V-53T Test 60 for Power, BMEP, and BSFC**

The differing engine set-up procedures do not allow direct engine performance comparisons between Test 39 and Test 60. The governor adjustment deviations between the two tests mask the performance deviations due to fuel variations alone.

Prior to test 60 a power curve on both neat JP-8 and JP-8 blended with 7.5% used oil was performed and comparisons between fuels on the same engine build can be made. Test 60 before-test deviations from blend to JP-8 fuel are presented in Figure 26 for fuel flow, power, and BSFC. The slight improvements in power with the JP-8 blend correspond with the increase in fuel consumption. Diesel engine fuel injection systems meter fuel by volume and deviations in engine power between fuels tend to correspond to fuel volumetric heating value. The difference in volumetric heating value between JP-8 and the JP-8 blend is 1.1%. Difference in fuel viscosity affects fuel injection due to leakage past the injector plunger. Some of the variations in fuel consumption and power are due to the viscosity deviation of the JP-8 and JP-8 blend. The BFSC represents the efficiency of the fuel conversion to power. The data suggest the 6V-53T engine conversion of the JP-8 blend fuel energy to power is equivalent to neat JP-8.

The comparison of the before and after engine performance curves for each fuel gives an indication of the fuels compatibility with the engine. In Figure 27, both fuels show an increase in fuel consumption after the 240-hour endurance cycle, which can be attributed to break-in and wear of the fuel injectors. The JP-8 blend shows a more consistent increase in fuel consumption across the range of engine speeds.

The power produced during the before and after test power curves for the JP-8 and JP-8 blend are shown in Figure 28. Both fuels show an increase in the power deviation as engine speed increases. For both fuels, the post-test power at lower speeds is equivalent or less than the pre-test power. The power increase for the post-test curves are partially attributed to engine run-in which typically reduces friction and the increase in fuel flow. The JP-8 blend shows a more consistent increase in post-test power at the higher engine speeds. These data suggest the JP-8 blend will not effect power production.

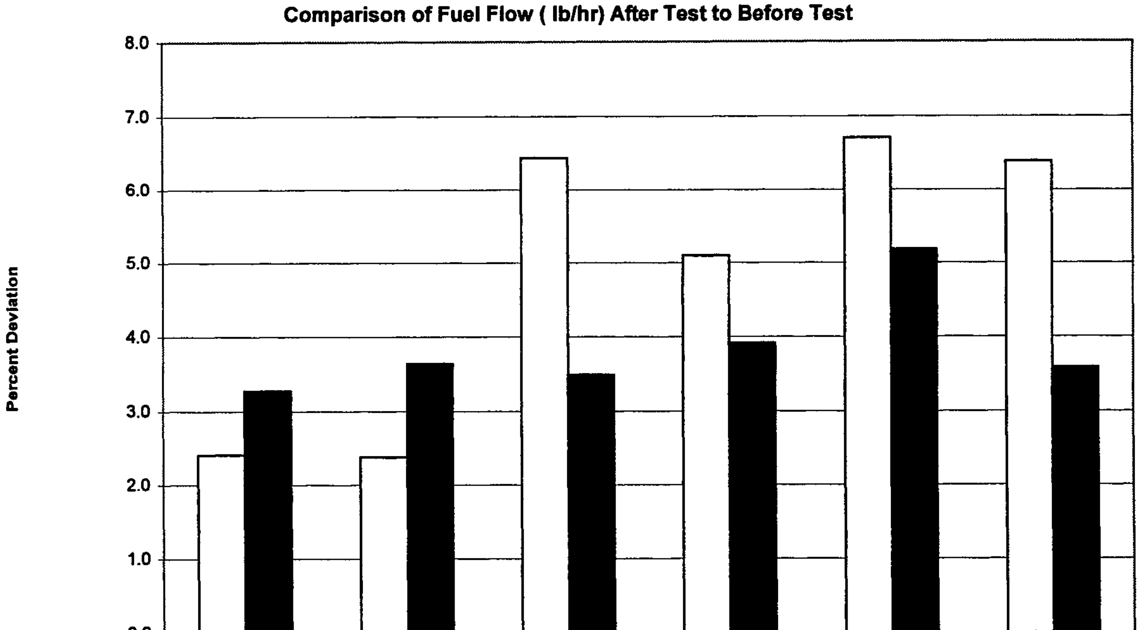


	1800	2000	2200	2400	2600	2800
□ fuel flow,lb/hr	2.2	2.8	2.3	2.2	1.5	2.2
■ power, bhp	2.3	2.2	1.9	1.9	1.8	2.3
▩ bsfc, lb/bhp-hr	-0.1	0.5	0.5	0.3	-0.3	-0.1

Engine Speed, RPM

Figure 26. Test 60 Deviations from JP-8/7.5%UO to JP-8 Before Test Power Curve

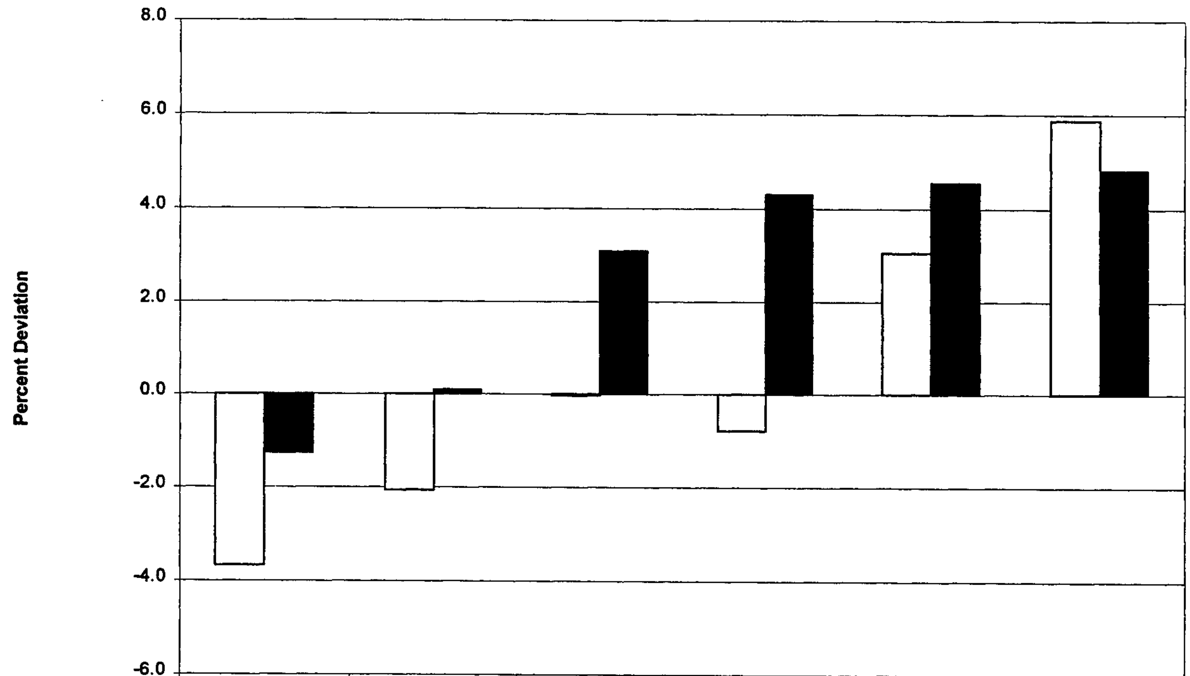
Comparison of Fuel Flow (lb/hr) After Test to Before Test



	1800	2000	2200	2400	2600	2800
□ JP-8	2.4	2.4	6.4	5.1	6.7	6.4
■ JP-8/7.5%UO	3.3	3.6	3.5	3.9	5.2	3.6

Engine Speed, RPM

Figure 27. Comparison of Fuel Flow (lb/hr) After Test to Before Test



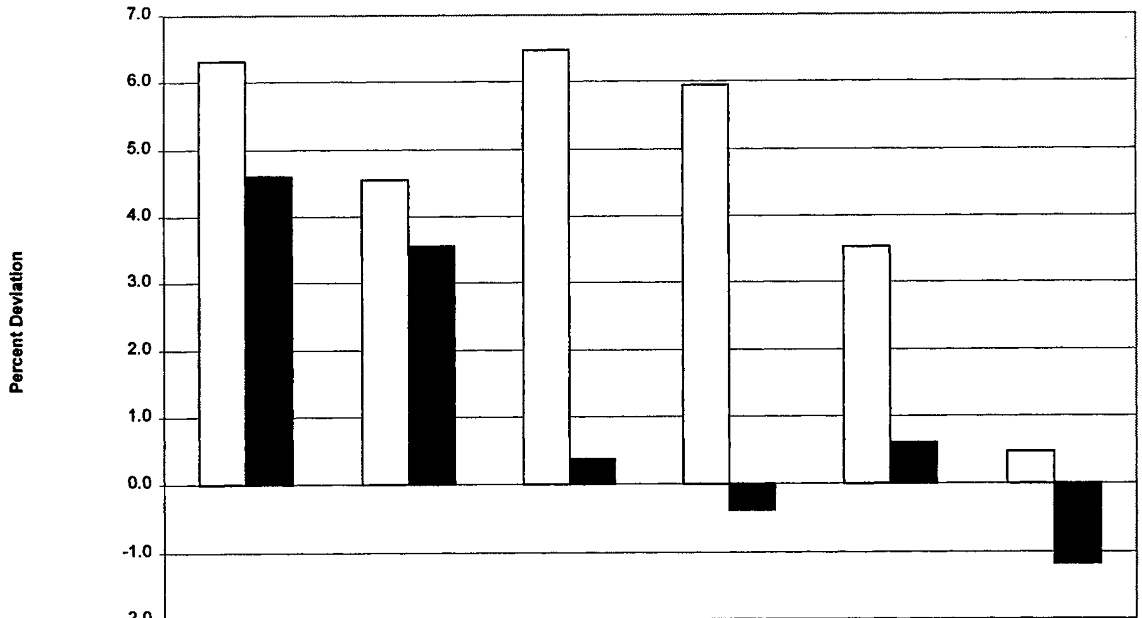
	1800	2000	2200	2400	2600	2800
□ JP-8	-3.7	-2.1	0.0	-0.8	3.1	5.9
■ JP-8/7.5%UO	-1.3	0.1	3.1	4.3	4.6	4.8

Engine Speed, RPM

Figure 28. **<u>Comparison of Power (bhp) After Test to Before Test</u>**

Figure 29 shows a comparison of BSFC after test to before test for both fuels. At higher engine rpm's, the neat JP-8 had an increase in BSFC, while the blend had little change in BSFC.

The brake specific fuel consumption for the before and after test power curves for the JP-8 and JP-8 blend are shown in Figure 27. Neat JP-8 shows an increase in post-test BSFC across the entire engine speed range. The JP-8 blend shows an increase in post-test BSFC at low engine speeds, and only nominal increases at high speeds. Increases in BSFC indicate a reduction in engine efficiency, which may be due to wear in the fuel injection system that affects the fuel injection timing. The post-test fuel injector inspections revealed the neat JP-8 test (Test 39) had one injector which had poor atomization, poor fuel spray, and low pop-off pressure. The bad injector in Test 39 affected the post-test performance curves. All other injectors from both tests revealed only minor post-test performance changes.



	1800	2000	2200	2400	2600	2800
□ JP-8	6.3	4.5	6.5	5.9	3.5	0.5
■ JP-8/7.5%UO	4.6	3.6	0.4	-0.4	0.6	-1.2

Engine Speed, RPM

Figure 29. <u>Comparison of BSFC (lb/hbp-hr) After Test to Before Test</u>

2. Engine Durability

The JP-8 blended with used oil contained amounts of wear metals and soot not normally present in JP-8 fuel. It was postulated that post-test ratings and measurements would show increases in deposits, resulting from the dirty oil, as well as increases in component wear, resulting from the metals in the fuel.

The use of blended fuel in the DD 6V-53T was found to have the most significant impact on the exhaust valves. The exhaust valves of the blended-fuel test show ash deposits, as well as vertical streaks, indicating imminent valve burning. Representative exhaust valve photos are shown in Fig 30. Complete photographs of Test 60 exhaust valves can be seen in Appendix D, Figures D-32 through D-37. The increase in deposits with the blended fuel is probably the result of soot, metals content, and ash that was brought to the fuel by the used oil.

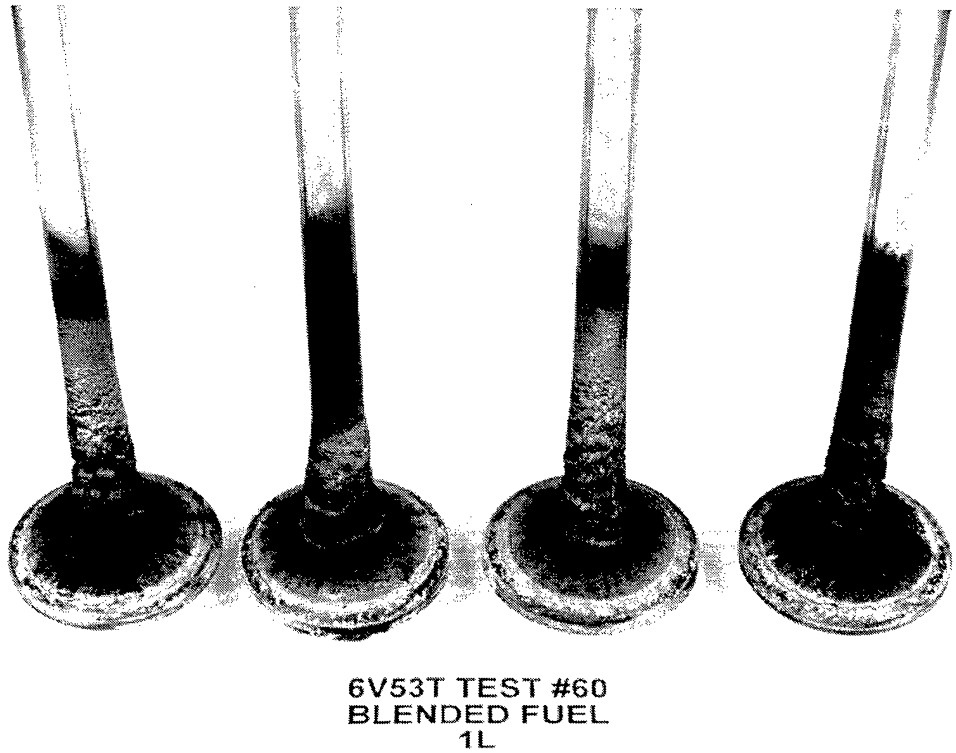


Figure 30a. <u>**Test 60 valves 1L**</u>

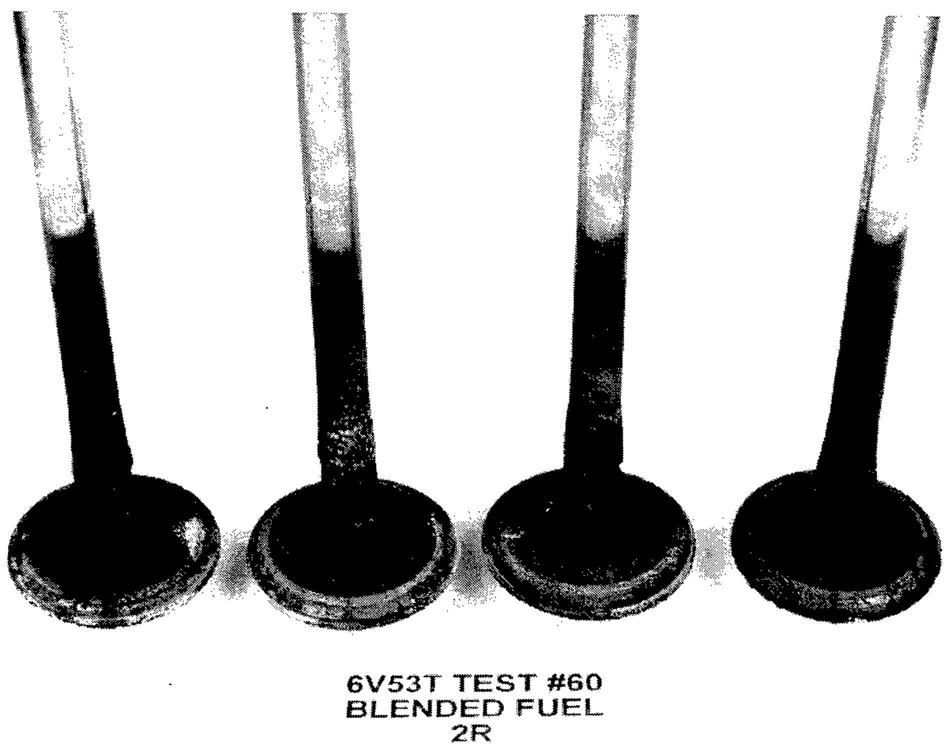


Figure 30b. <u>**Test 60 valves 2R**</u>

The Piston Weighted Total Demerits (WTD) method was used to quantify varnish and carbon deposits on the pistons in the ring groove and land areas. The WTD ratings showed no substantial difference between the pistons tested with neat JP-8 and those tested with blended fuel (Figure 31).

Figure 32 shows the main and rod bearing weight losses for Tests 39 and 60. The bearing weight losses are judged to be nearly equivalent between Tests 39 and 60.

Figure 33 shows that less liner scuffing occurred when the engine was operated with the blended fuel. Here, the used oil in the blend is benefiting the fuel by acting as a lubricant within the cylinder. Piston ring end gap change, a measurement of ring wear, also decreased under operation with the blended fuel (Figure 34). However, ring face distress (Figure 35) and ring radial width wear (Figure 36) increased when the blended fuel was used.

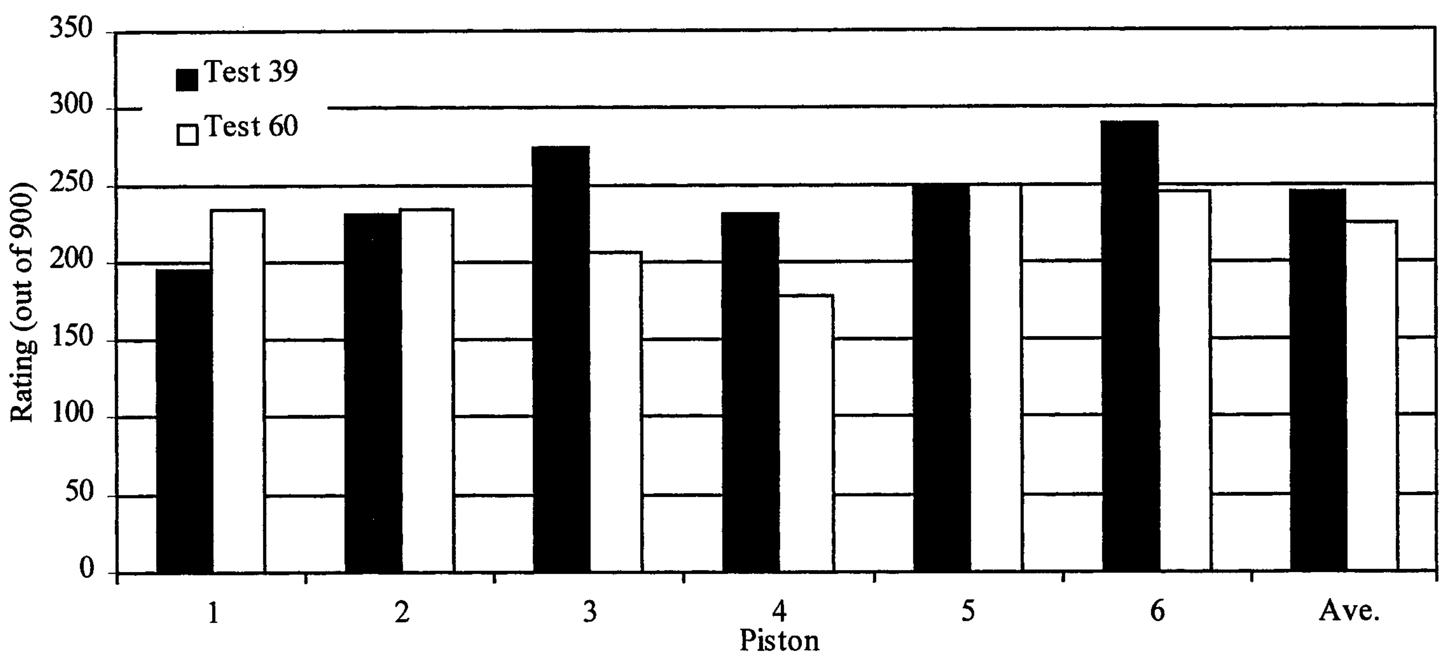


Figure 31. Piston Weighted Total Deposits (Demerits, Tests 39 and 60)

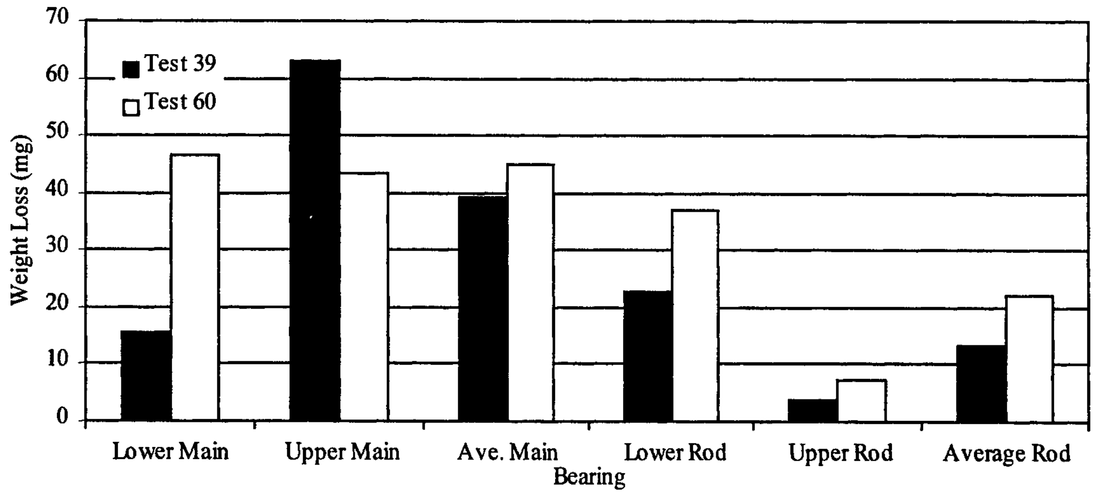


Figure 32. Bearing Weight Loss, Tests 39 and 60

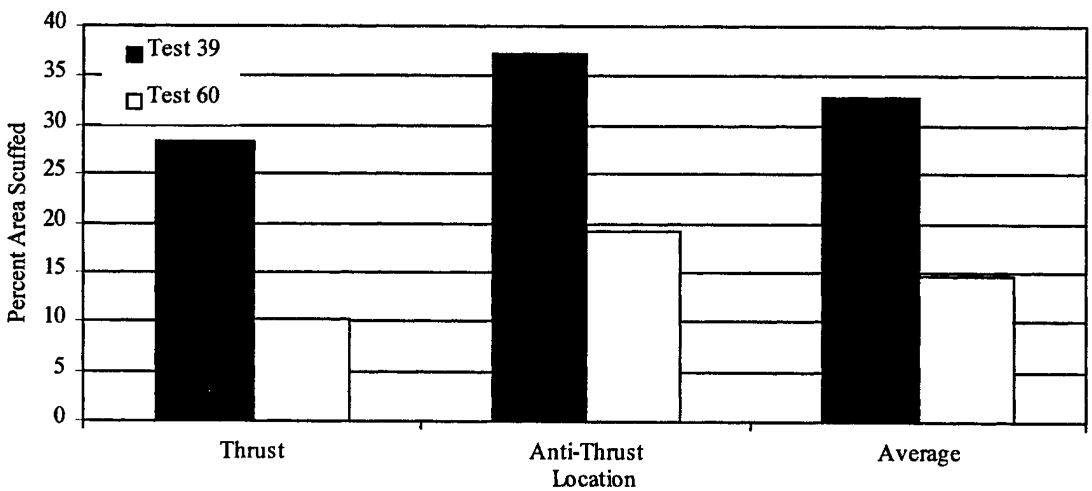


Figure 33. Cylinder Liner Scuffing, Test 39 and Test 60

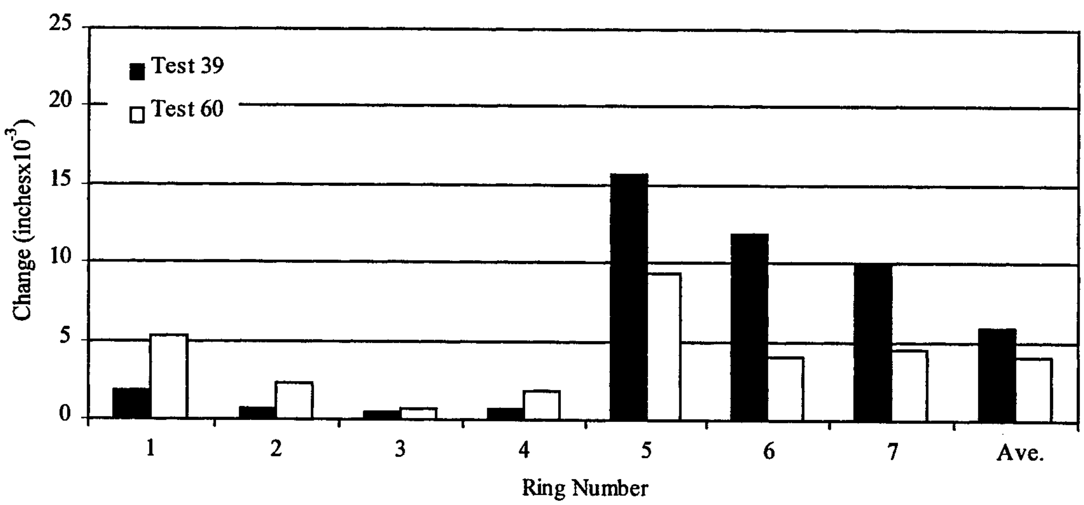


Figure 34. Piston Ring End Gap Change, Test 39 and Test 60

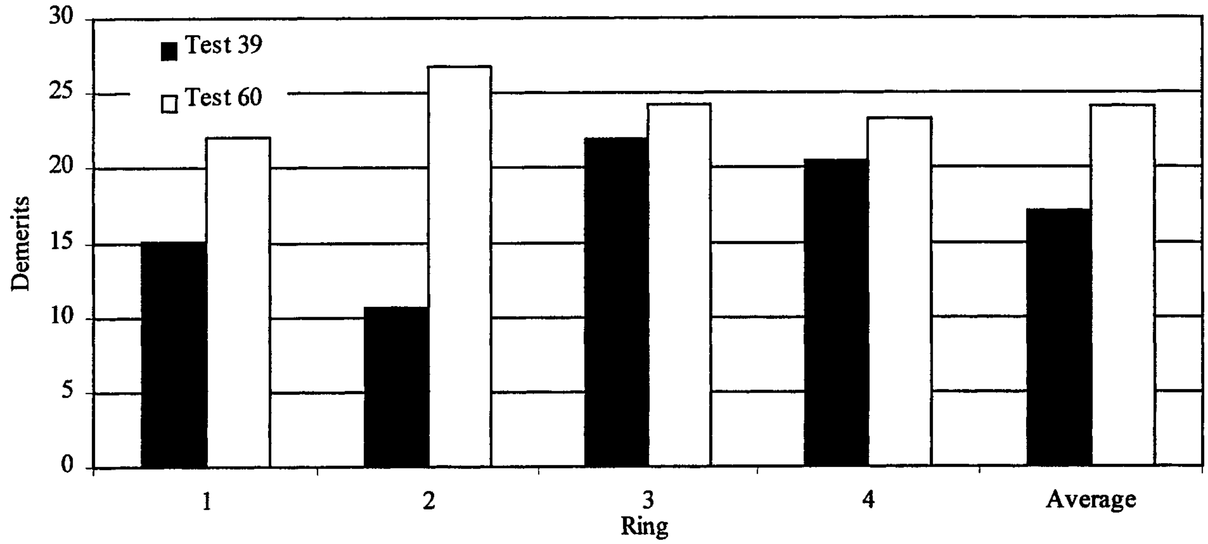


Figure 35. Ring Face Distress, Test 39 to Test 60

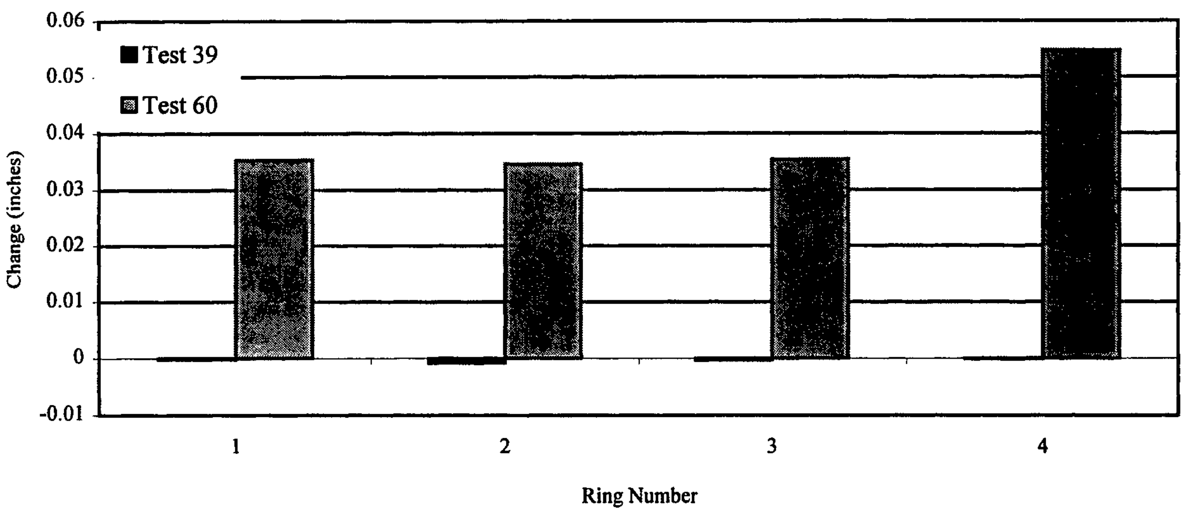


Figure 36. Ring Radial Width Wear, Tests 39 and 60

3. Lubricant Analysis

During the tests and at the completion of both tests, the engine crankcase oil was tested to determine viscosity, total acid and base numbers, and wear metal content. There were no major differences in lubricant wear metal contents between the neat JP-8 test and blended fuel test. The Total Acid Numbers (TAN) for the two tests were similar, while the Total Base Numbers (TBN) for the blended-fuel test were somewhat lower than the TBN for

the neat fuel. The viscosities of the used oils were similar at both 40°C and 100°C. Based on the analysis of the used crankcase engine oil from the endurance tests, the addition of used oil to the JP-8 fuel did not have a major impact on used engine crankcase oil condition.

4. Fuel Injection System

The use of used oil blended with JP-8 fuel did not appear to have affected the fuel injectors during Test 60. Injector calibration did not change, and both before and after the test leak down time remained above specifications, and the spray pattern (atomization) was good.

VI. SUMMARY AND CONCLUSIONS

During this study, the GM 6.2L and the DD 6V-53T engines were used for dynamometer endurance tests to evaluate the effects of adding 7.5% vol. used oil to JP-8 fuel. The conclusions are summarized as follows:

1. No major changes in engine power were observed during operation with blended fuel.
2. At the end of the 6.2L endurance test using blended fuel, BSFC at 3600 rpm was increased 7.2% compared to start of test. At 2100 and 2400 RPM, BSFC at end of test was increased substantially with blended fuel as compared to neat JP-8. These effects are believed to be attributed to the partially clogged pre-chamber exits observed when using the blended fuel.
3. Liner scuffing was reduced when using the blended fuel in the 2-cycle diesel engine.
4. Unusual amounts of ashy deposits were found in both engines after being tested with blended fuel. In the 6.2L engine, the deposits were found in the pre-combustion chamber. In the 6V-53T engine, deposits and preburning streaks were found on the exhaust valves.

5. The fuel injection system of the DD 6V-53T engine was not affected by the blended fuel. In the 6.2L engine, fuel injectors fell below the minimum leak back time after using blended fuel. Calibration of the 6.2L fuel pump changed very little during the tests.
6. No major impact on crankcase oil properties was observed in either engine using the blended fuel.
7. The following analysis was conducted to relate the accelerated endurance test results to anticipated Army operation:
   - For the 6.2L engine –1700 gallons of blended fuel were consumed. The HMMWV has a 25-gallon fuel tank; therefore, 68 tanks of blend were consumed. The vehicle would only operate on blended fuel after an oil change. We assume an average of 1 or 2 oil changes per year. Thus, the 6.2L engine experienced the equivalent of 34 to 68 years of operating on 1 to 2 tanks of blended fuel per year.
   - For the 6V53T engine-3,000 gallons of blended fuel were consumed. A typical vehicle might have a fuel tank of 154 gallons. This would be 19 tanks of blended fuel. At one oil change per year, this is equivalent to 19 years operation.
8. The endurance tests produced no "show-stoppers" with respect to engine conditions.
9. For both engines, condition was such that continuous use of 7.5 %vol blend would not be recommended. Considering it would take between 19-68 years for an Army engine to reach the end of endurance test condition, use of blended fuel 1 or 2 times per year is judged acceptable from an endurance standpoint.

VII. RECOMMENDATIONS

The most significant problem identified using blended JP-8 and 7.5% vol. used oil was the ashy deposits found at the end of both tests. Soot and ash contained in the used oil are the probable cause of these deposits; improved clean-up of the used oil before

blending with fuel would improve engine durability. Also, evaluations of engine operation on blended fuel should be determined in a field test.

VIII. LIST OF REFERENCES

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2. U.S. Military Specification MIL-T-83133B, Turbine Fuel, Aviation, Kerosene Type, Grade JP-8, September 1987.

3. Coordinating Research Council, Inc., "Development of Military Fuel/Lubricant/Engine Compatibility Test," Final Report, New York, NY, January 1967.

4. U.S. Military Specification MIL-L-2104F, "Lubricating Oil, Internal Combustion Engine, Tactical Service."

5. Federal Test Method Standard 791C, "Lubricants, Liquid Fuels, and Related Products: Methods of Testing," 30 September 1986.

6. Likos, W.E., Owens, E.C., and Lestz, S.J., "Laboratory Evaluation of MIL-T-83133 JP-8 Fuel in Army Diesel Engines," Interim Report BFLRF No. 232, AD A205281, Contract No. DAAK70-87-C-0043, TARDEC Fuels and Lubricants Research Facility, Southwest Research Institute, San Antonio, TX, January 1988.

APPENDIX A
6.2L Neat JP-8 Fuel Evaluation –Test 97-1

Baseline, GM 6.2L Engine

Test Lubricant: AL-24610-L
Test Fuel: JP-8 (AL-24508-F)
Test No.: 97-1
Date: November, 1996

Conducted For

U.S. Army Tank-Automotive Research, Development and Engineering Center
Logistics Equipment Directorate
Fort Belvoir, Virginia 22060-5606

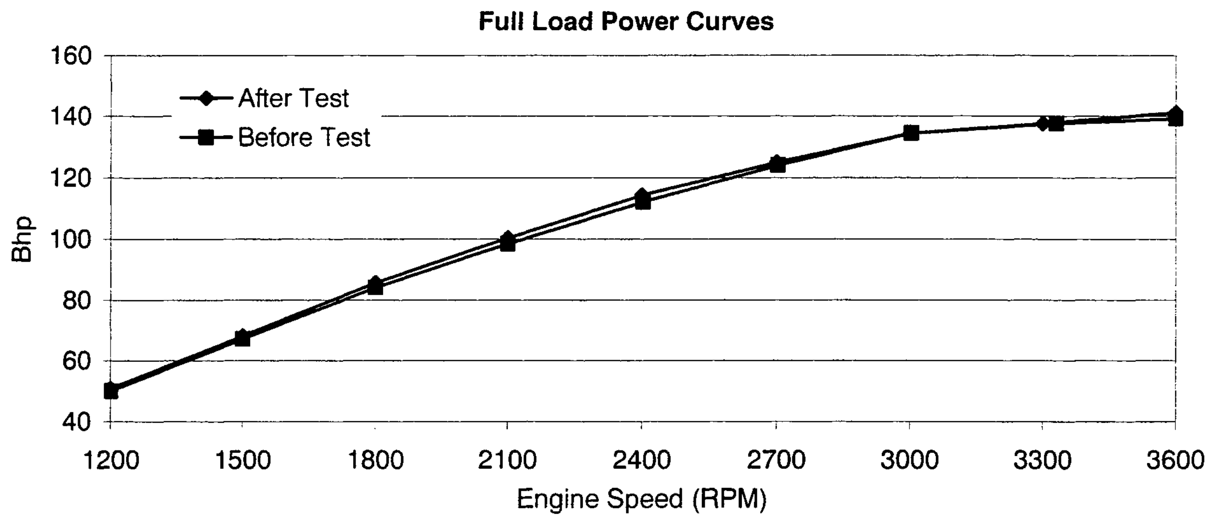
By

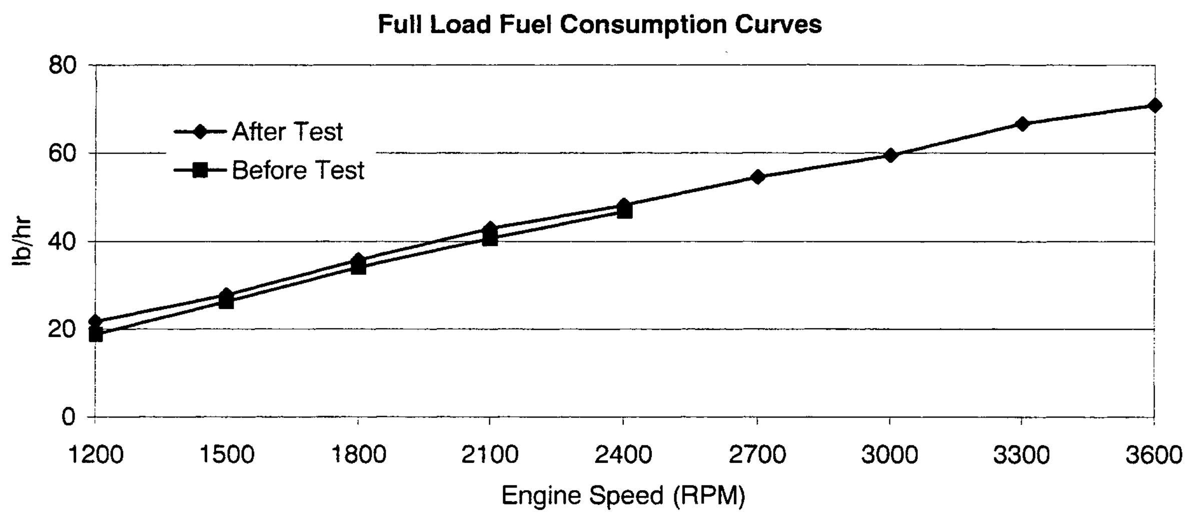
TARDEC Fuels and Lubricants Research Facility (SwRI)
Southwest Research Institute
P.O. Drawer 28510
San Antonio, Texas 78228-0510

GM 6.2L
97-1
ENGINE REBUILD MEASUREMENTS*
SERIAL NUMBER: 3HMV712

	Minimum	Maximum	Average	Specified Limits
Cylinder Block Bore				
Inside Diameter (Bottom)	3.9769	3.9783	3.9775	3.9759 - 3.9789
Out of Round	0.0003	0.0011	0.0006	0.0008 Max
Taper	0.0000	0.0003	0.0001	0.0008 Max
Piston Clearances				
Bores 1-6	0.0034	0.0039	0.0036	0.0035 - 0.0045
Bores 7-8	0.0042	0.0045	0.0044	0.0040 - 0.0050
Piston Ring Groove Clearance				
Second	0.002	0.002	0.002	0.0015 - 0.0030
Oil	0.002	0.002	0.002	0.0016 - 0.0038
Piston Ring End Gap				
Top	0.020	0.025	0.022	0.012 - 0.022
Second	0.036	0.041	0.038	0.029 - 0.039
Oil	0.017	0.023	0.020	0.010 - 0.020
Piston Pin				
Diameter	1.2204	1.2206	1.2205	1.2203 - 1.2206
Clearance	0.0004	0.0006	0.0005	0.0004 - 0.0006
Fit in Rod	0.0008	0.0004	0.0006	0.0003 - 0.0012
Camshaft				
Diameter Bearings 1-4	2.1675	2.1680	2.1678	2.1678 - 2.1688
Diameter Bearing 5	N/A	N/A	2.0102	2.0099 - 2.0109
Clearance	0.0025	0.0032	0.0028	0.0015 - 0.0044
Crankshaft				
Journal Diameter 1-4	2.9496	2.9497	2.9496	2.9495 - 2.9504
Journal Diameter 5	N/A	N/A	2.9498	2.9493 - 2.9502
Out-of-Round	0.0000	0.0001	0.0000	0.0002 Max
Clearance 1-4	0.0023	0.0033	0.0028	0.0018 - 0.0033
Clearance 5	N/A	N/A	0.0031	0.0022 - 0.0031
Crankpin				
Diameter	2.3981	2.3982	2.3982	2.3981 - 2.3992
Out-of-Round	0.0000	0.0001	0.0001	0.0002 Max
Clearance	0.0031	0.0037	0.0034	0.0018 - 0.0039
Valves				
Stem Clearance - Intake	0.0016	0.0021	0.0018	0.001 - 0.0027
Stem Clearance - Exhaust	0.0020	0.0027	0.0024	0.001 - 0.0027

* Note: Measurements are in inches





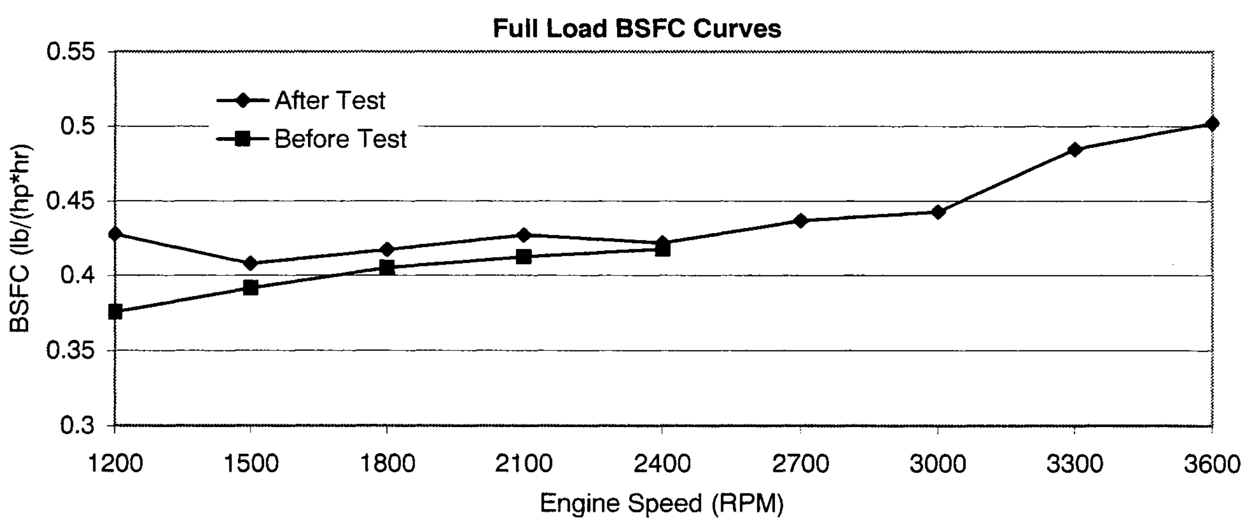


Figure A-1. <u>Full Load Performance</u>

GM 6.2L
97-1
Operating Conditions Summary
Serial Number: 3HMV712

	Maximum Power Mode (3600 RPM)		Idle Mode (800 RPM)	
	Mean	Standard Deviation	Mean	Standard Deviation
Engine Speed, rpm	3574.35	39.38	897	32
Torque, ft-lb	206.78	4.29	22.32	2.73
Fuel Consumption, lb/hr	71.59	1.11	3.72	0.395
Observed Power, Bhp	135.61	3.05	0.844	0.757
BSFC, lb/Bhp-hr	0.528	0.631	5.83	2.95
Oil Galley Pressure, psi	62.63	4.27	44.38	5.31
Temperatures, °F				
Water Jacket Inlet	159.96	3.33	163.06	8.55
Water Jacket Outlet	179.93	2.1	175.58	5.88
Oil Sump	235.23	6.76	192.86	8.87
Fuel Inlet	95.24	5.74	94.38	6.22
Air Inlet	94.28	9.4	87.43	7.71
Exhaust Temperatures, °F				
Cylinder 1	1153.8	17.41	231.28	15.64
Cylinder 2	1156.27	17.35	231.74	15.67
Cylinder 3	1170.94	17.46	245.25	15.55
Cylinder 4	1161.82	23.82	259.5	16.82
Cylinder 5	1202.15	21.1	235.33	16.87
Cylinder 6	1169.15	24.72	233.89	18.93
Cylinder 7	1180.29	31.13	244.99	16.07
Cylinder 8	1180.16	19.1	228.2	17.07
Common	1161.52	31.23	210.76	15.63

GM 6.2L
Test 97-1
FUEL ANALYSIS
Fuel: AL-24805-F*

Property		ASTM Method	Value
API Gravity at 60°F		D 1298	44.5
Particulates, mg/100 mL		D 5452	0.7
Distillation, °C	IBP	D 86	150.5
	10%	D 86	172.8
	20%	D 86	179.7
	30%	D 86	187.6
	40%	D 86	194.8
	50%	D 86	202.1
	60%	D 86	210.4
	70%	D 86	219.3
	80%	D 86	229
	90%	D 86	241.6
	End Point	D 86	262.9
	Residue, vol%	D 86	1
Flash Point, °C		D 93	44
Cetane Number		D 613	46.9
Kinematic Viscosity at 40°C, cSt		D 445	1.28
Cu Corrosion, at 100°C		D 130	1A
Total Acid Number		D 664	<0.01
Sulfur, wt%		D 4294	0.03
Net Heat of Combustion, Btu/lb		D240	19,772
Existent Gum, mg/100 mL		D 381	2.5
Ash, wt%		D 482	<0.001
Accelerated Stability, mg/100mL		D 2274	0.4
Lubricity:	HFRR, mm	ISO	0.645
	SLWT, kg	ARMY	2100

* Analysis was performed on AL-24717-F, from same batch as AL-24805-F but delivered to TFLRF separately.

GM 6.2L
97-1
LUBRICANT ANALYSIS
Lubricant: AL-24610-L

	ASTM Test Method	Test Time, Hours				
		0	70	140	154	210
Kinematic Viscosity at 40°C (104°F) cSt	D 445	109.39	126.59	211.83	207.00	133.43
Kinematic Viscosity at 100°C (212°F) cSt	D 445	14.60	13.94	19.41	19.57	14.91
Total Acid Number mg KOH/g	D 664	1.76	4.27	7.59	6.33	4.31
Total Base Number mg KOH/g	D 4739	5.58	1.10	0.55	1.19	1.34

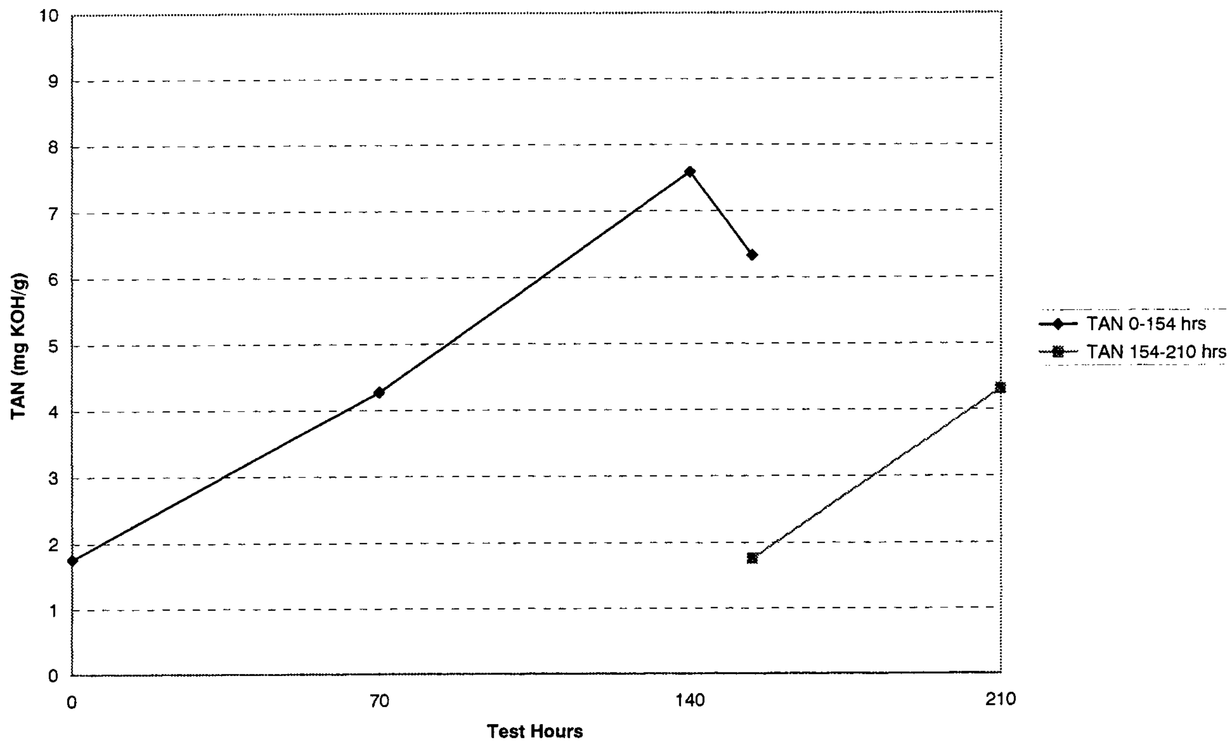


Figure A-2. <u>Test 97-1 Total Acid Number</u>

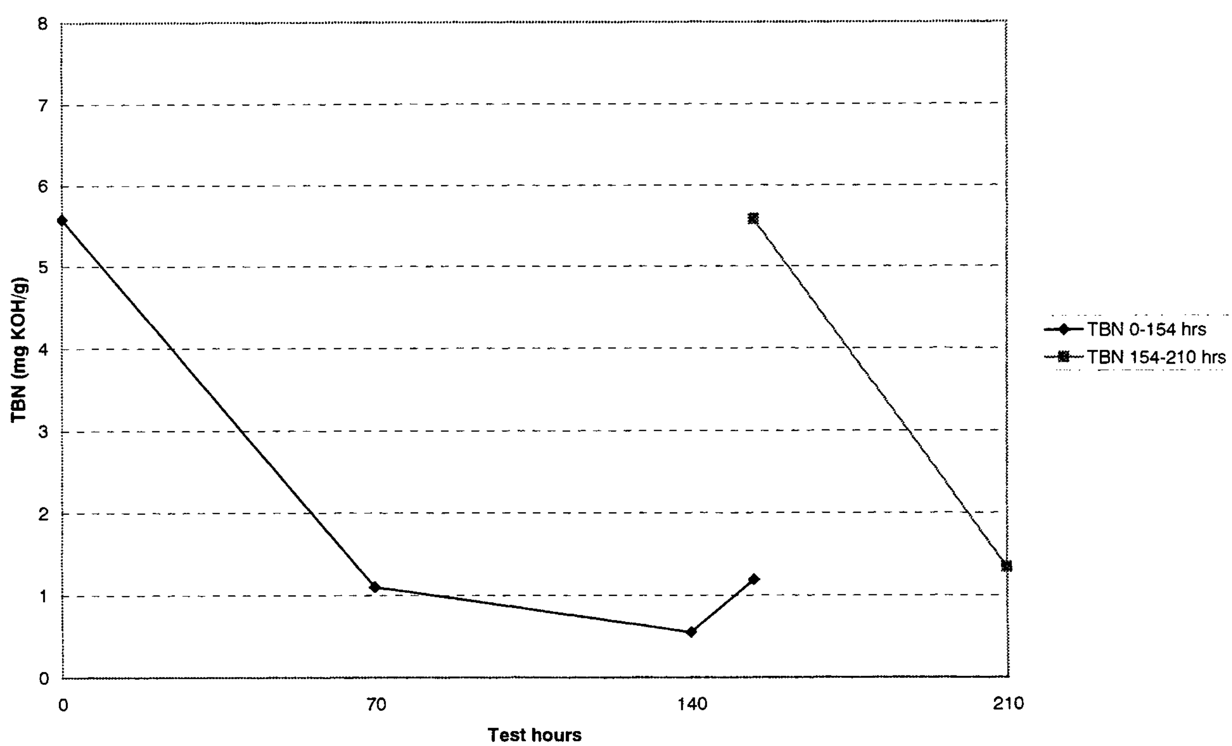


Figure A-3. <u>Test 97-1 Total Base Number</u>

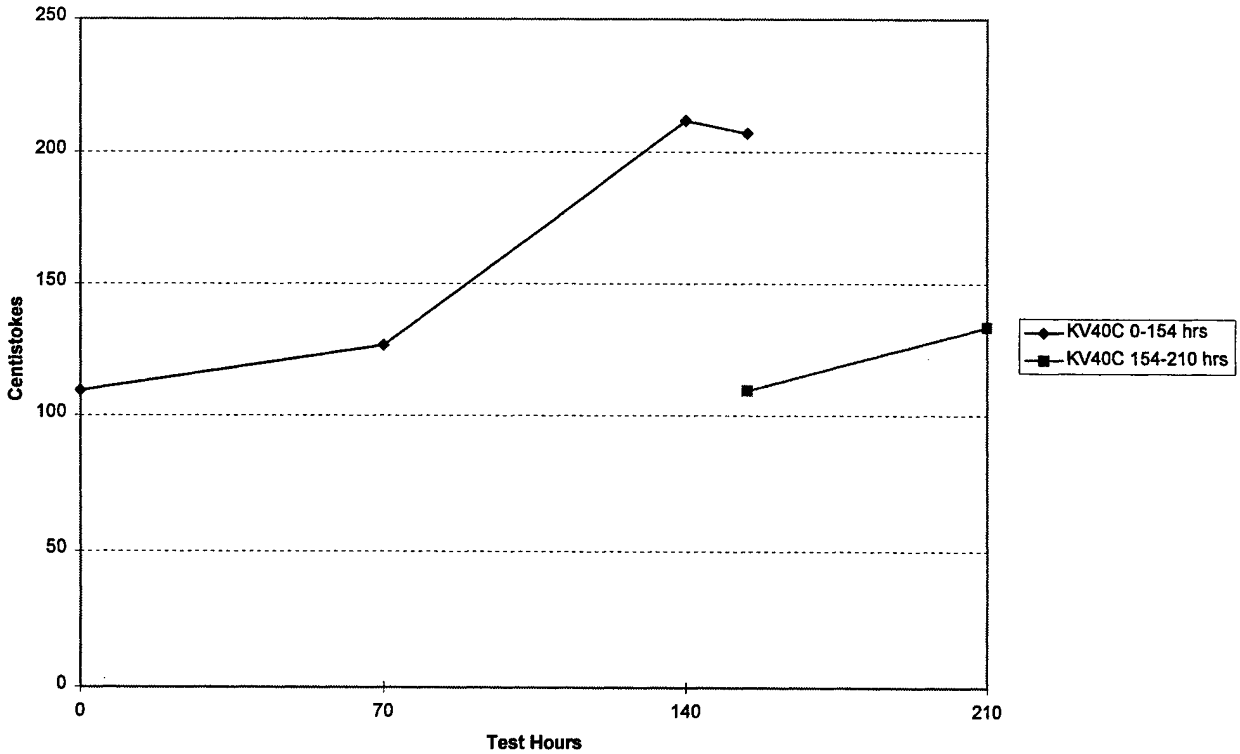


Figure A-4. <u>**Test 97-1 Kinematic Viscosity at 40°C**</u>

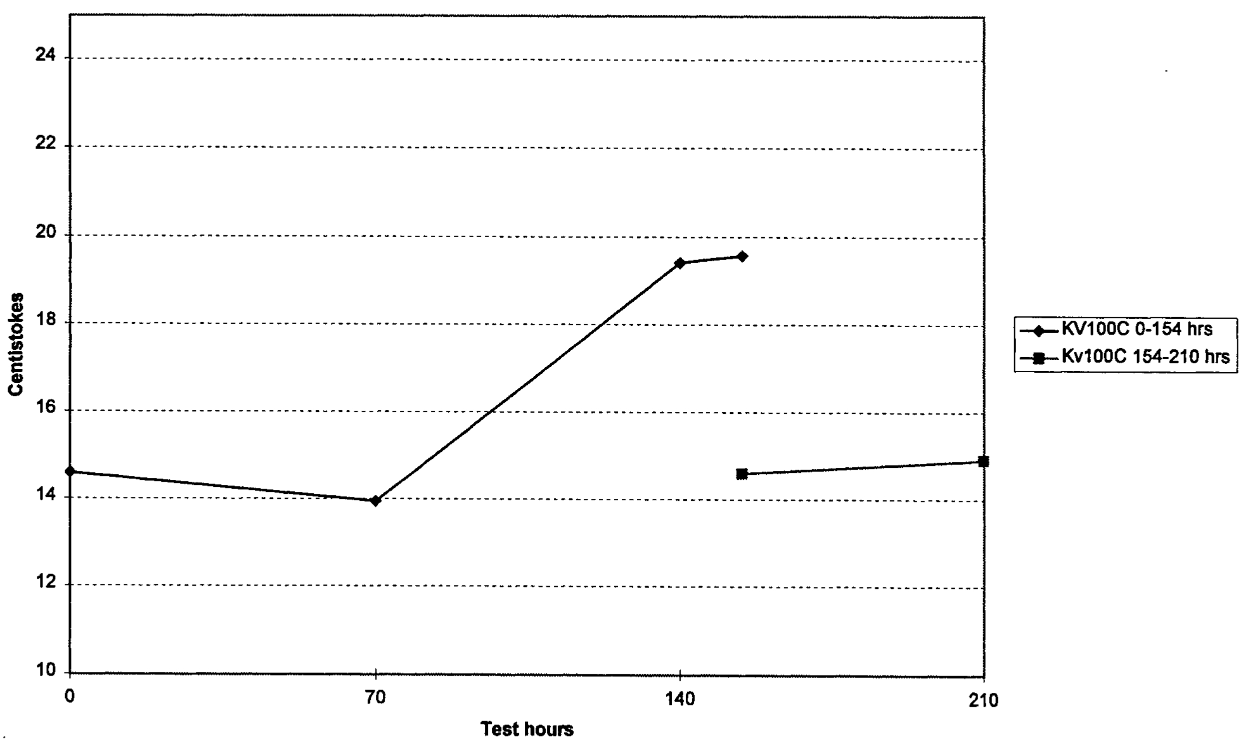


Figure A-5. <u>**Test 97-1 Kinematic Viscosity at 100°C**</u>

GM 6.2L
97-1
TOTAL CONSUMPTION AND WEAR METALS BY XRF
Lubricant: AL-12610-L

Test Time, Hours	Oil Consumed, lb	Wear Metals, ppm Fe	Cu	Pb
0	0.00	82	22	2
14	0.00	152	57	2
28	0.00	163	64	5
42	5.51	231	71	13
56	2.47	205	68	15
70	2.31	217	64	19
84	1.74	234	87	28
98	2.58	287	101	52
112	2.16	376	136	72
126	1.86	450	154	103
140	3.40	529	203	142
154	1.51	532	205	171
168	1.06	83	57	27
182	2.38	99	52	25
196	2.94	117	57	28
210	0.01	126	54	31

Total oil consumed: 29.96 lb
Average oil consumption rate: 0.143 lb/hr

NOTE: Oil was changed at 154 hours.
* X-ray fluorescence spectroscopy

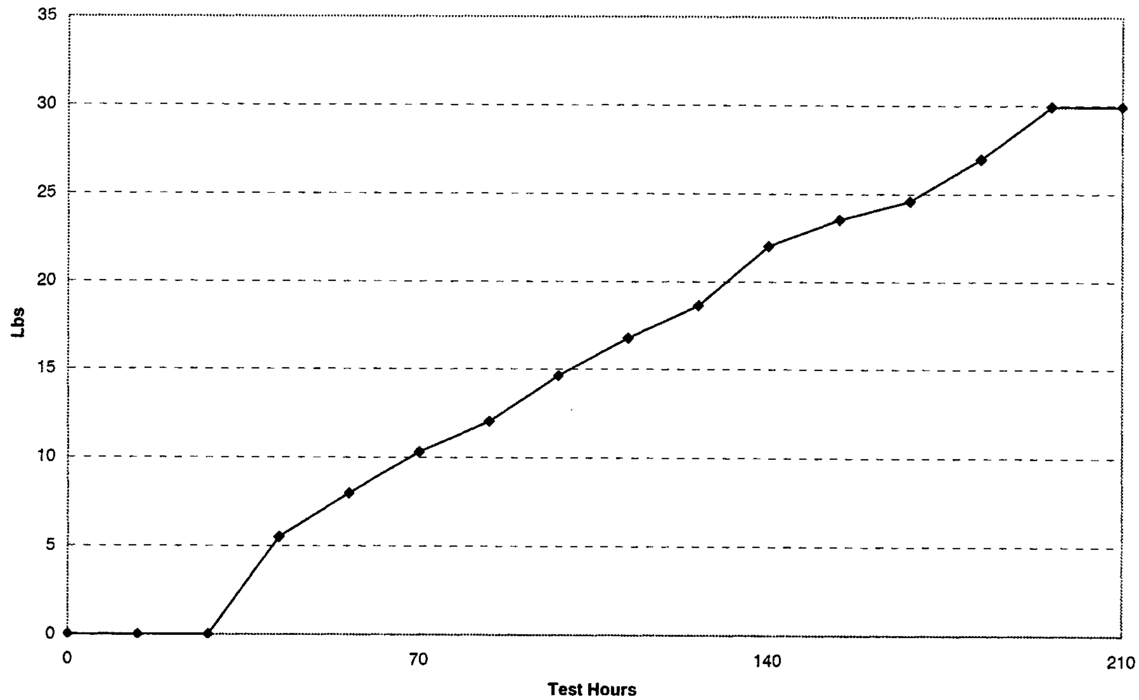


Figure A-6. <u>Test 97-1 Cumulative Oil Consumption</u>

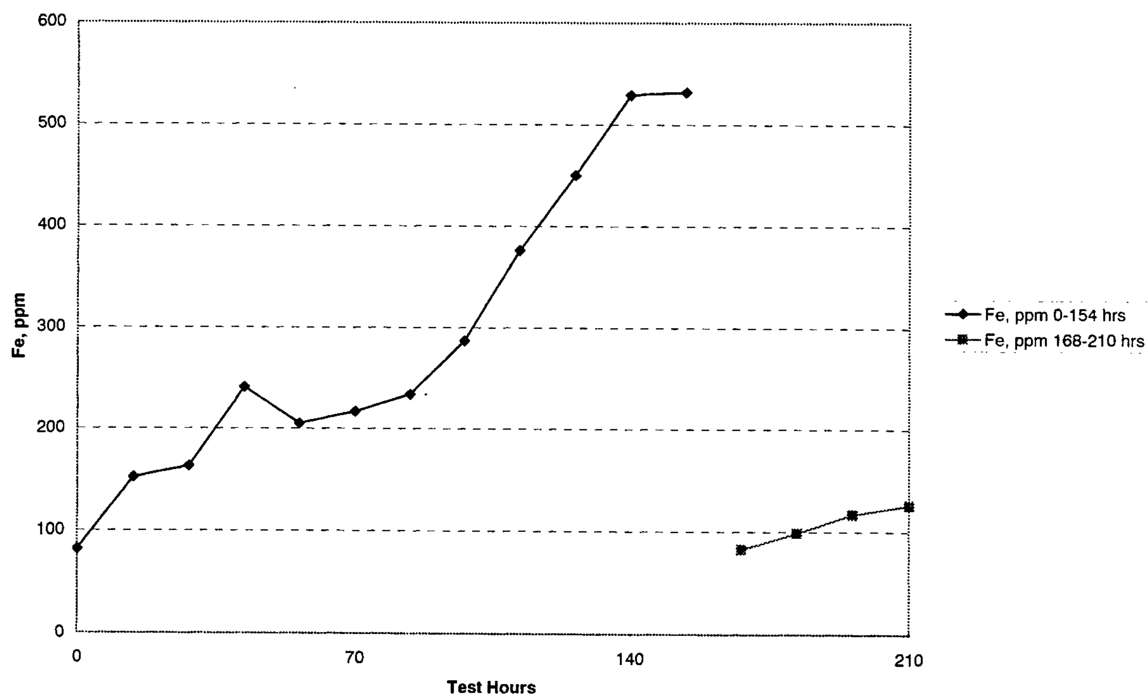


Figure A-7. <u>Test 97-1 Iron Wear Metal</u>

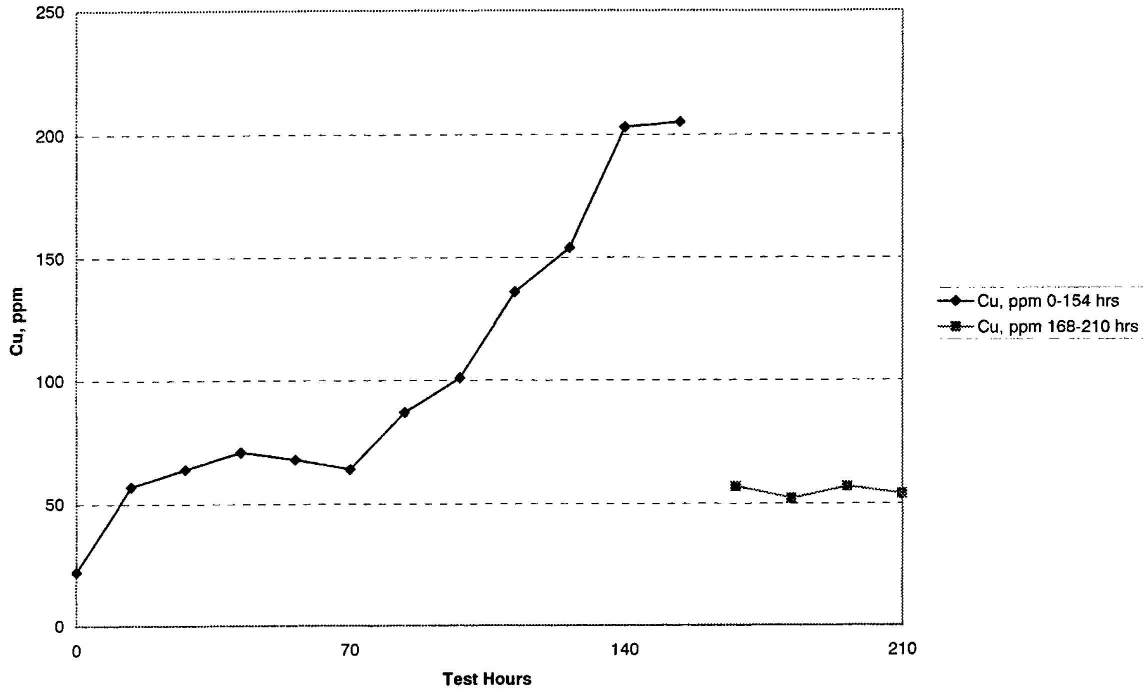


Figure A-8. Test 97-1 Copper Wear Metal

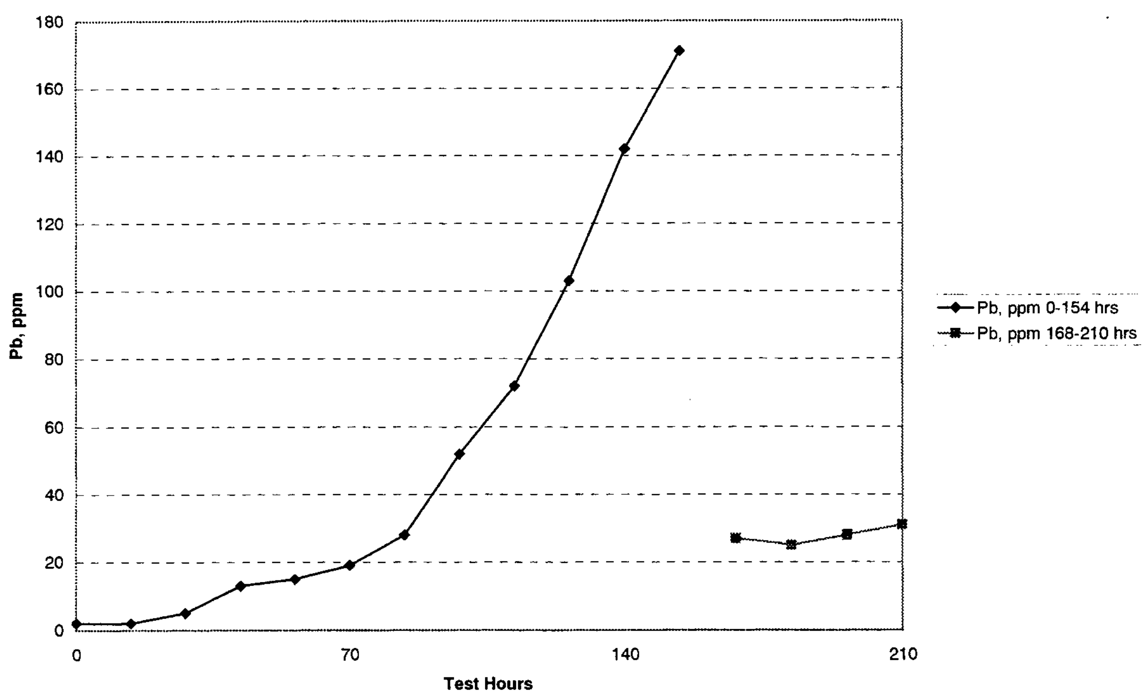


Figure A-9. Test 97-1 Lead Wear Metal

GM 6.2L
97-1
WEAR MEASUREMENTS*
Lubricant: AL-12610-L

Cylinder Liner Bore Diameter Change

	1		3		5		7	
	T-AT**	F-B	T-AT	F-B	T-AT	F-B	T-AT	F-B
Top	0.0012	0.001	0.0004	0.0032	0.0033	0.0049	0.0027	0.0027
Middle	0.0005	0.0006	0.0005	0.0038	0.0017	0.0037	0.0023	0.0025
Bottom	0.0012	0.0007	0.0014	0.0031	0.0009	0.0029	0.0015	0.002

	2		4		6		8	
	T-AT	F-B	T-AT	F-B	T-AT	F-B	T-AT	F-B
Top	0.0037	0.0022	0.0038	0.0038	0.0082	0.0074	0.0023	0.0025
Middle	0.0024	0.0014	0.0027	0.0040	0.0036	0.0053	0.0016	0.0025
Bottom	0.0013	0.0012	0.0012	0.0033	0.0020	0.0043	0.0006	0.0023

Average Change

	T-AT	F-B
Top	0.0032	0.0035
Middle	0.0019	0.0030
Bottom	0.0014	0.0025

Overall average change: 0.0026

Piston Ring End Gap Change

Ring	1	2	3	4	5	6	7	8	Average
Top	0.028	0.038	0.032	0.06	0.046	0.067	0.039	0.034	0.043
Second	0.003	0.003	0.005	0.011	0.008	0.011	0.008	0.008	0.007
Oil	0.045	0.034	0.031	0.053	0.044	0.050	0.044	0.034	0.042

Overall average change: 0.031

Keystone Top Ring Proudness

1	2	3	4	5	6	7	8	Average
-0.0009	-0.0021	0.0006	-0.0011	-0.0002	0.0011	0.0003	0.0018	-0.0001

Bearing Weight Change, g

Main Bearings	1	2	3	4	5	Average Change
Upper	0.0527	0.0527	0.0680	0.0468	0.0939	0.0628
Lower	0.0458	0.1850	0.2802	0.0604	0.1269	0.1397

Overall average change: 0.1012

Rod Bearings	1	2	3	4	5	6	7	8	Average
Upper	0.0493	0.0855	0.0916	0.1007	0.0923	0.0431	0.0853	0.0474	0.0744
Lower	0.0227	0.0229	0.0406	0.0519	0.0392	0.0232	0.0323	0.0233	0.0320

Overall average change: 0.0532

Valve Recession

Valve	1	2	3	4	5	6	7	8	Average
Intake	-0.0003	0.0036	0.0043	0.0052	0.0013	-0.0012	0.0001	-0.0014	0.0015
Exhaust	0.0017	-0.0006	-0.0008	-0.0020	-0.0013	-0.0020	-0.0020	-0.0021	-0.0011

Overall average change: 0.0002

*All dimensions are given in inches.
**T-AT=Thrust-Antithrust Direction; F-B= Front-Back Direction.

GM 6.2L
97-1
POST TEST ENGINE CONDITION AND DEPOSITS
Lubricant: AL-12610-L

	Cylinder Number 1	2	3	4	5	6	7	8	Average
Cylinder Liner									
Liner Scuffing, % Area									
%Total Area Scuffing	95.0	100.0	100.0	100.0	100.0	75.0	100.0	100.0	96.3
Thrust	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Anti-Thrust	90.0	100.0	100.0	100.0	100.0	50.0	100.0	100.0	92.5
Pistons									
Top Groove Fill, %	51.0	60.0	85.0	90.0	77.0	70.0	74.0	80.0	73.4
Int. Groove Fill, %	6.0	23.0	33.0	39.0	29.0	36.0	24.0	20.0	26.3
Weighted Deposit, 1K	288.9	323.3	385.5	398.6	344.3	602.0	330.3	424.0	387.1
Ring Condition	Fair	Bad	Fair	Bad	Bad	Bad	Fair	Fair	
Valves									
Intake	6.5	6.3	6.8	6.0	6.6	6.5	6.0	6.0	6.3
Exhaust	8.5	8.5	8.5	8.5	9.6	8.5	9.6	8.5	8.8
Combustion Chamber Deposits									
Merit Rating	7.60	7.30	7.52	7.38	7.27	7.58	7.60	7.35	7.45
Prechamber Deposits, g	0.0733	0.0481	0.0618	0.0652	0.0565	0.0603	0.0244	0.1528	0.0678
Bearing Surface									
Main Bearings, % Wear, % Scratched, Pitting*									
Upper	0%,50%LS	0%,0%	5%,1%VLS	0%,1%VLS	5%,5%VLS				
Lower	0%,15%LS	20%,10%LS	0%,1%LS	0%,10%LS	15%,15%LS,P				
Rod Bearing, % Wear, % Scratched, Pitting									
Upper	5%,2%LS	15%,1%LS,P	20%,2%LS	3%,3%HS	15%,2%MS	0%,0%	10%,2%MS	0%,1%LS	
Lower	0%,1%VLS	0%,1%VLS	0%,3%LS	0%,3%HS	0%,2%MS	0%,0%	0%,1%VLS	0%,0%	

* VLS = Very Light Scratching, LS = Light Scratching, MS = Medium Scratching, HS = Heavy Scratching, P = Pitting

GM 6.2L
Test 97-1
FUEL INJECTOR TESTS
Fuel: AL-24508

	Cylinder Number								
	1	2	3	4	5	6	7	8	Average
Pop-Off Pressure, Psi (1500 min)									
Before Test	1850	1850	1850	1850	1875	1850	1825	1850	1850
After Test	1625	1650	1650	1700	1675	1650	1650	1675	1659
Leak Back Time, seconds (10 min)									
Before Test	21	17	16	21	28	19	21	19	20
After Test	22	13	16	20	28	16	23	22	20
Fuel Pump Calibration									
(cc/1000 strokes) @ 1000 RPM									
Before Test	49								
After Test	48								
Overall Change	1								
(cc/1000 strokes) @ 1800 RPM									
Before Test	90								
After Test	88								
Overall Change	2								

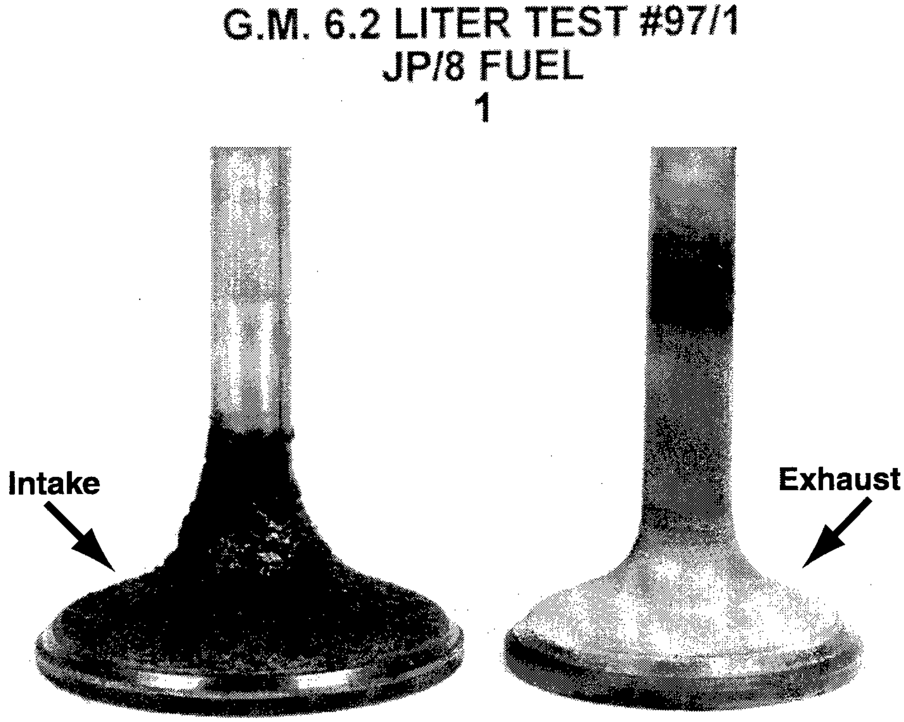


Figure A-10. G.M. 6.2 Liter Test #97/1, JP-8 Fuel, Cylinder 1 Valves

Figure A-11. G.M. 6.2 Liter Test #97/1, JP-8 Fuel, Cylinder 4 Valves

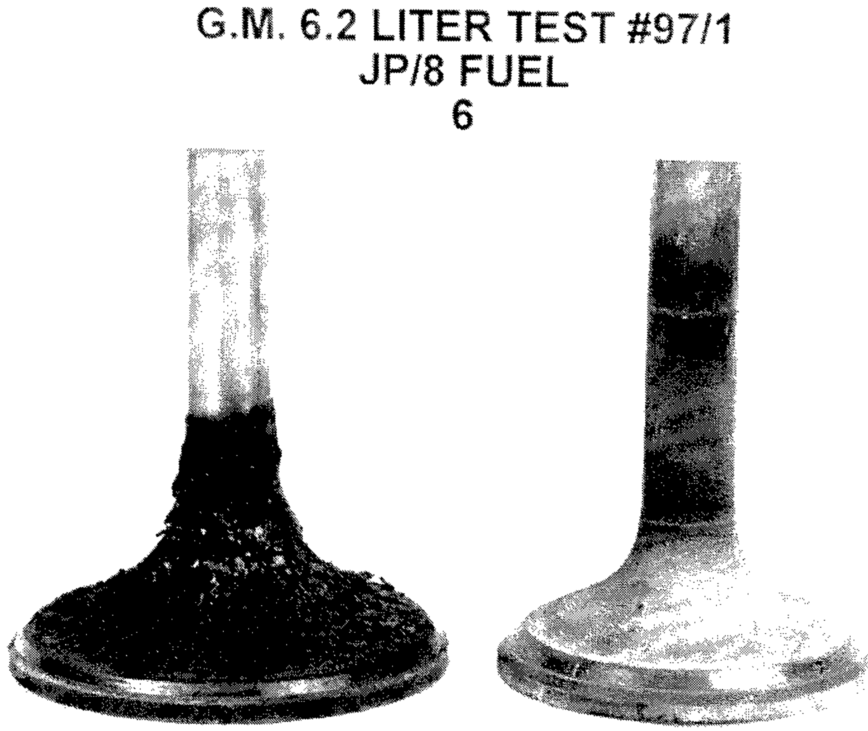


Figure A-12. <u>**G.M. 6.2 Liter Test #97/1, JP-8 Fuel, Cylinder 6 Valves**</u>

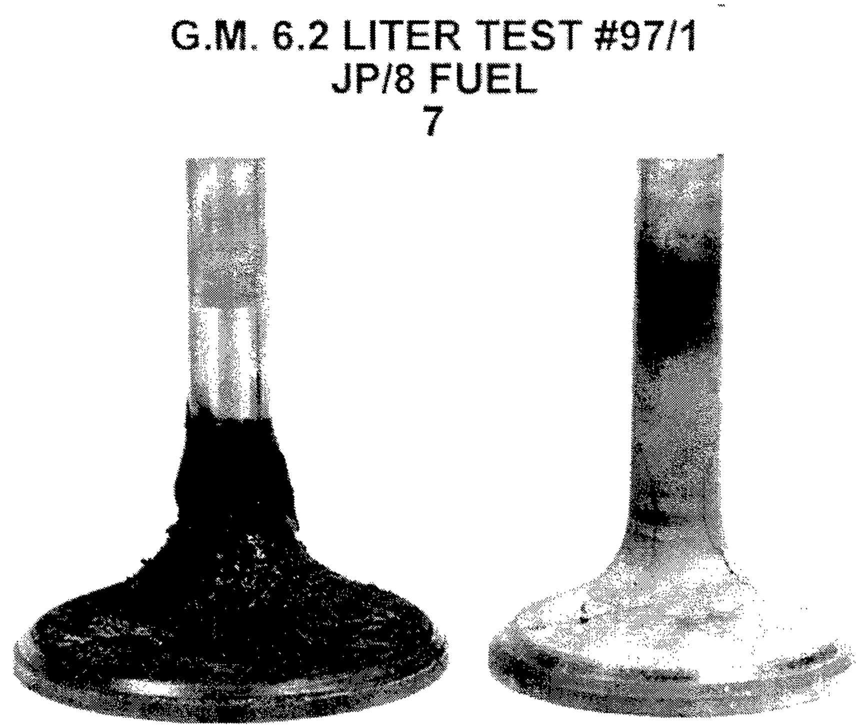


Figure A-13. <u>**G.M. 6.2 Liter Test #97/1, JP-8 Fuel, Cylinder 7 Valves**</u>

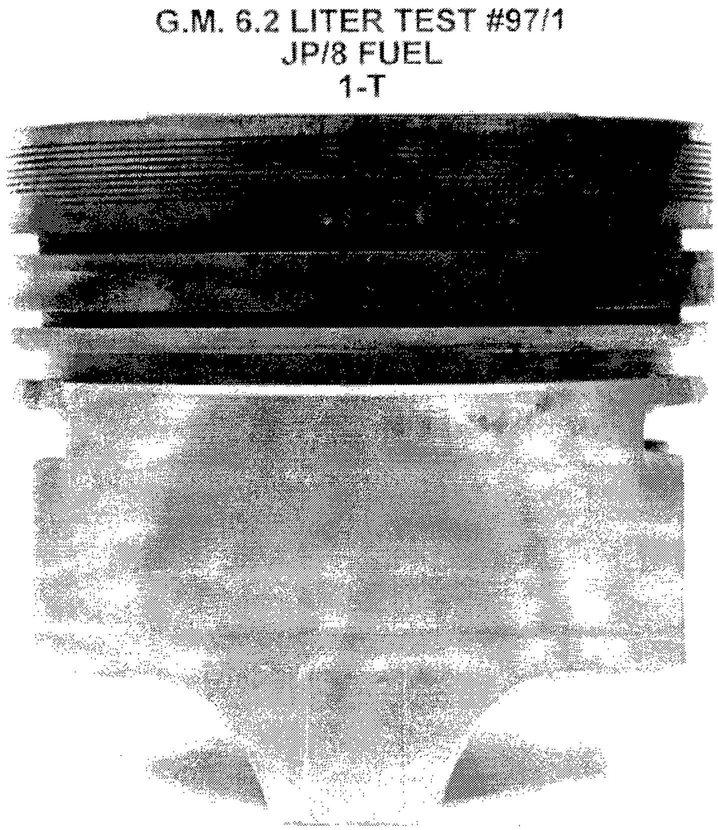


Figure A-14. G.M. 6.2 Liter Test 97-1, JP-8 Fuel, Piston 1-T

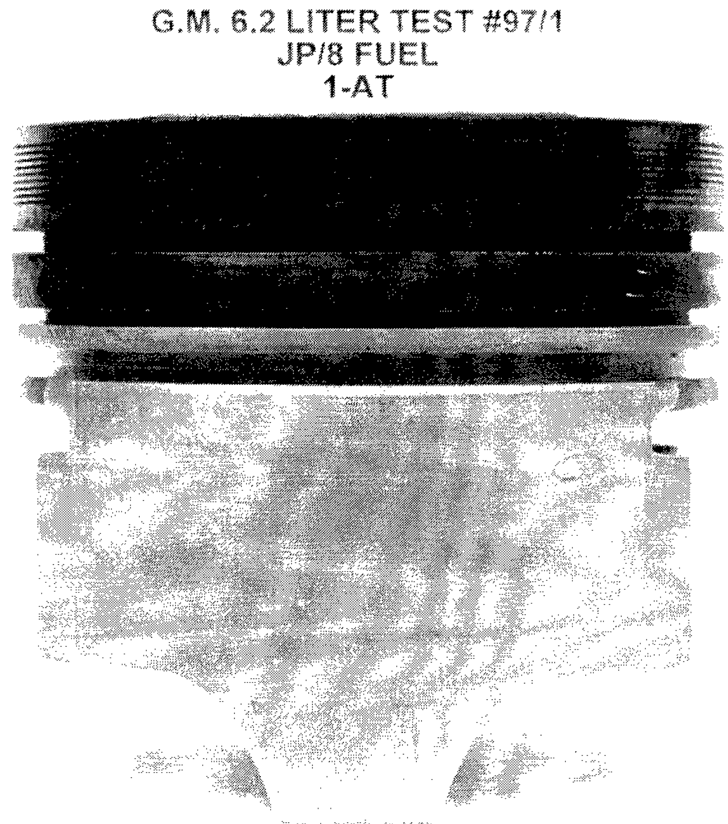


Figure A-15. G.M. 6.2 Liter Test 97-1, JP-8 Fuel, Piston 1-AT

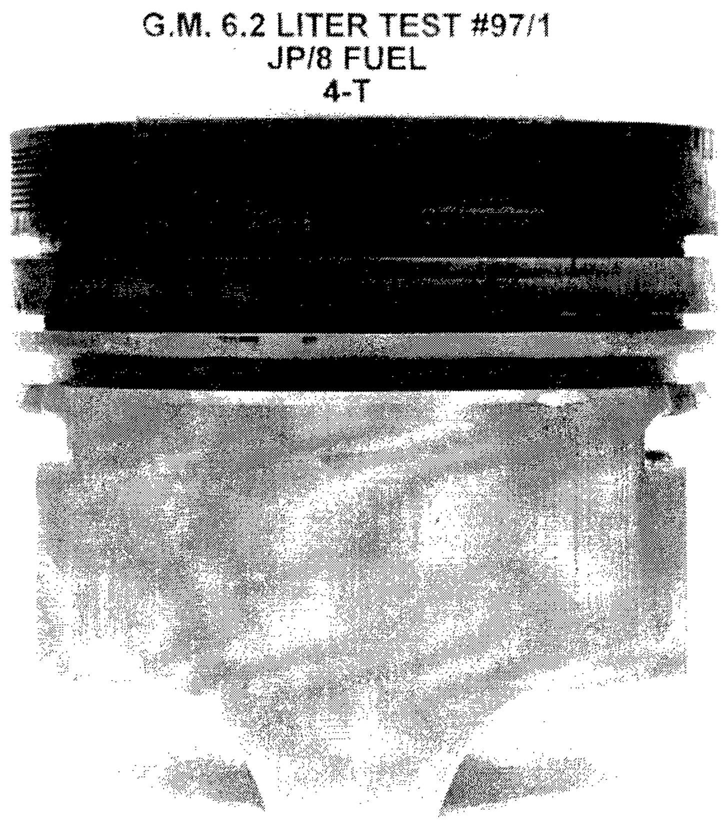


Figure A-16. G.M. 6.2 Liter Test 97-1, JP-8 Fuel, Piston 4-T

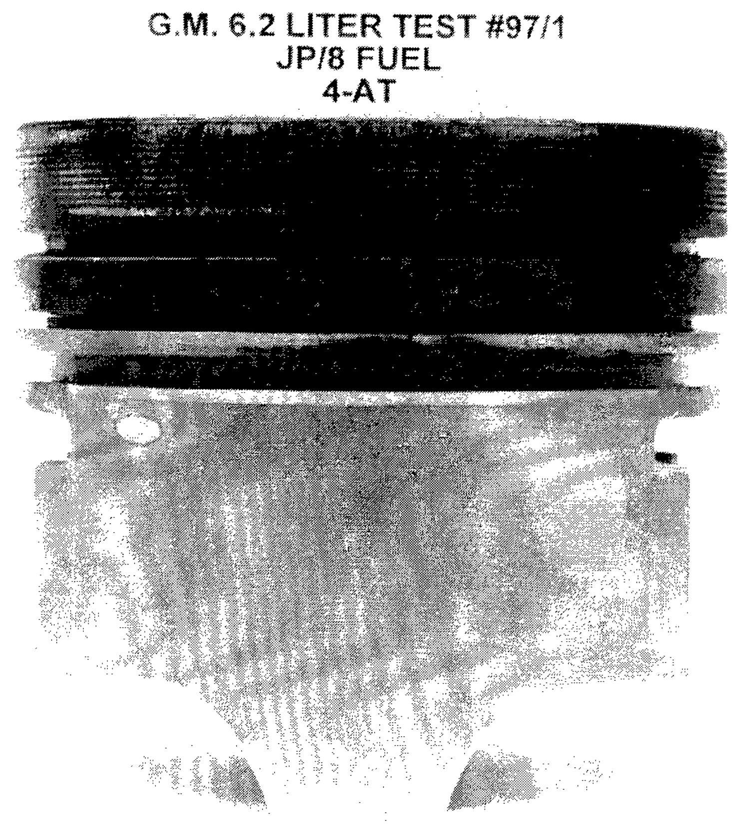


Figure A-17. G.M. 6.2 Liter Test 97-1, JP-8 Fuel, Piston 4-AT

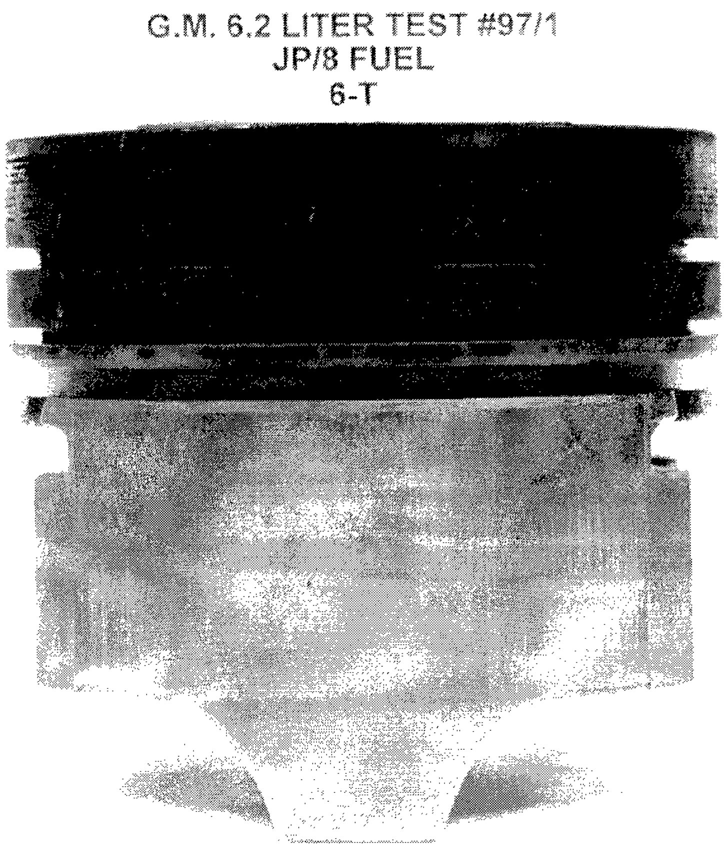


Figure A-18. G.M. 6.2 Liter Test 97-1, JP-8 Fuel, Piston 6-T

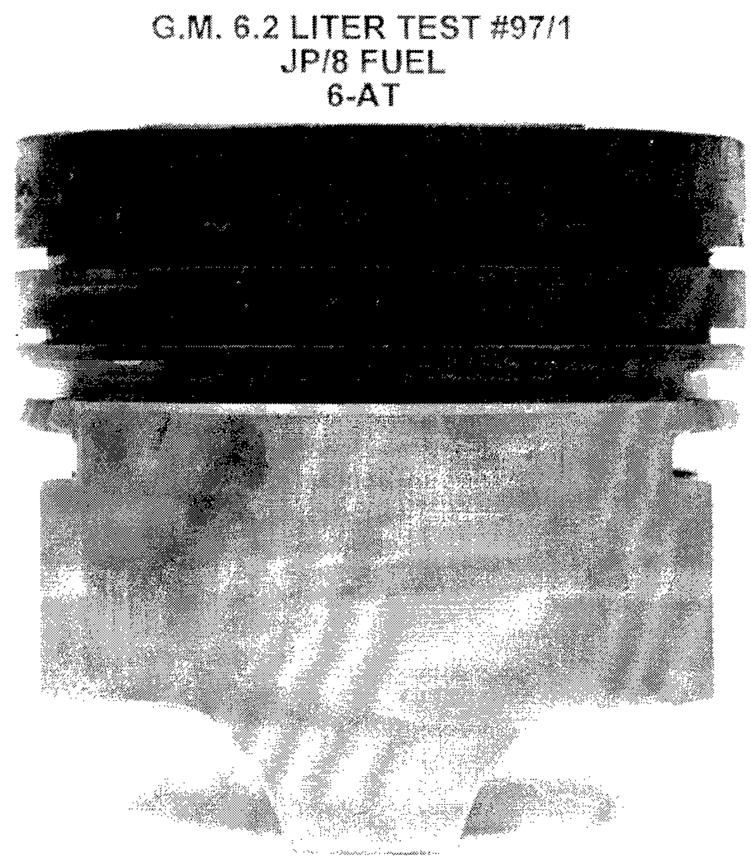


Figure A-19. G.M. 6.2 Liter Test 97-1, JP-8 Fuel, Piston 6-AT

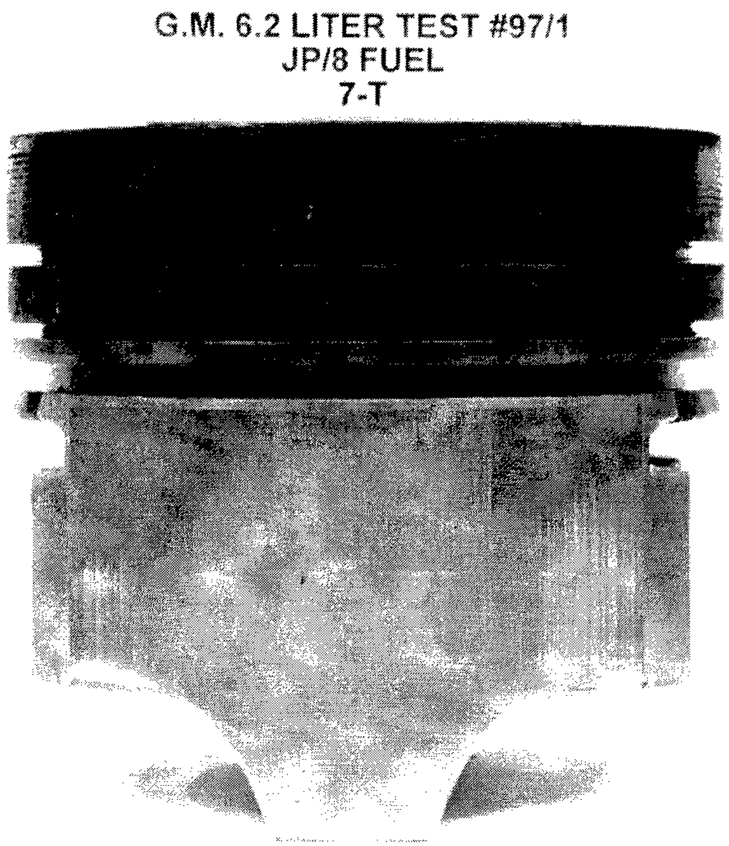


Figure A-20. G.M. 6.2 Liter Test 97-1, JP-8 Fuel, Piston 7-T

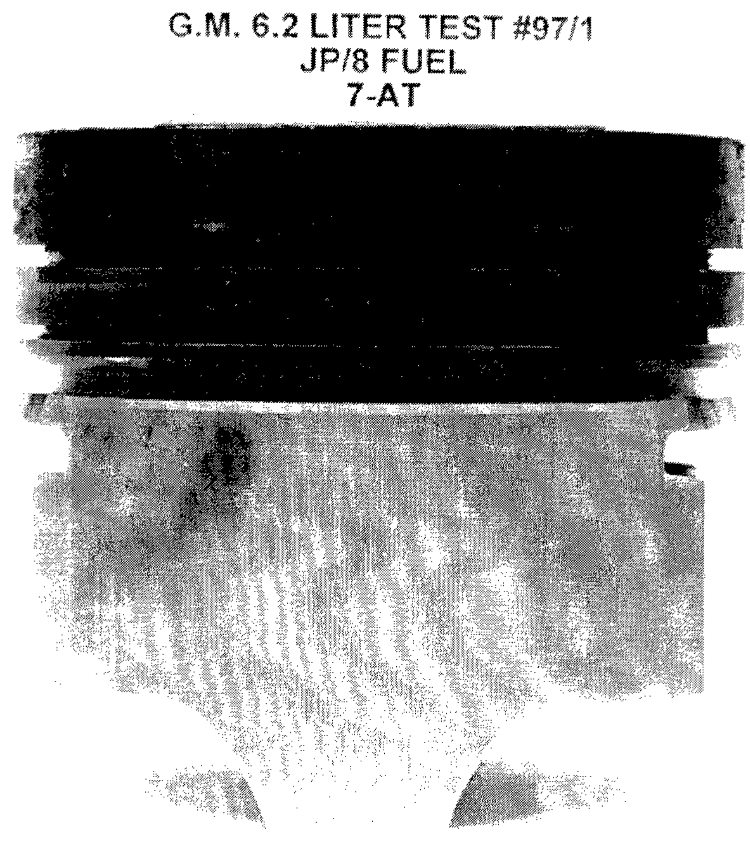


Figure A-21. G.M. 6.2 Liter Test 97-1, JP-8 Fuel, Piston 7-AT

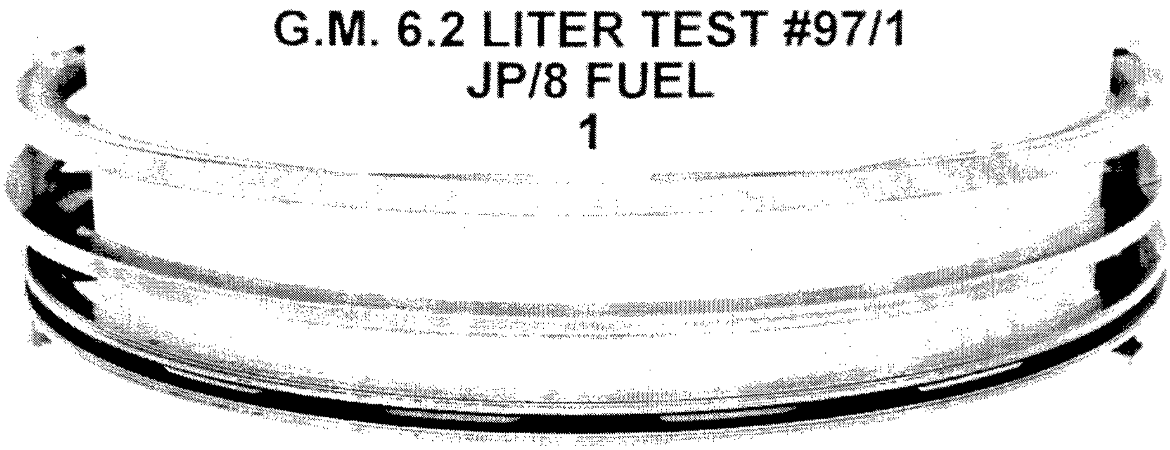


Figure A-22. <u>G.M. 6.2 Liter Test 97-1, JP-8 Fuel, Cylinder 1 Rings</u>

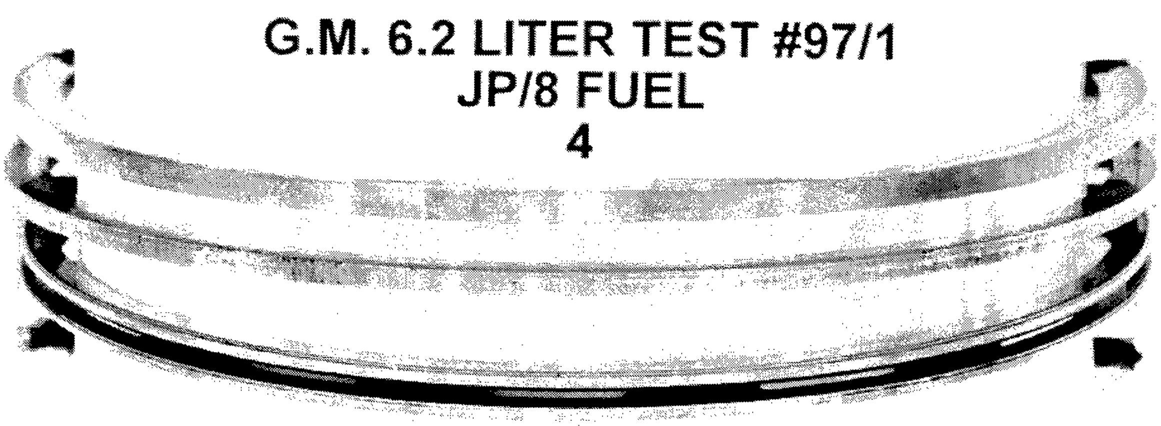


Figure A-23. <u>G.M. 6.2 Liter Test 97-1, JP-8 Fuel, Cylinder 4 Rings</u>

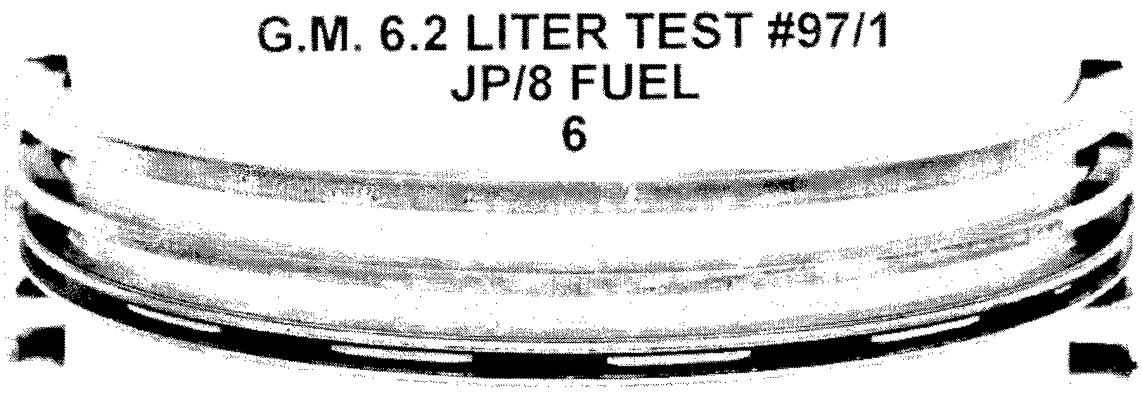


Figure A-24. <u>G.M. 6.2 Liter Test 97-1, JP-8 Fuel, Cylinder 6 Rings</u>

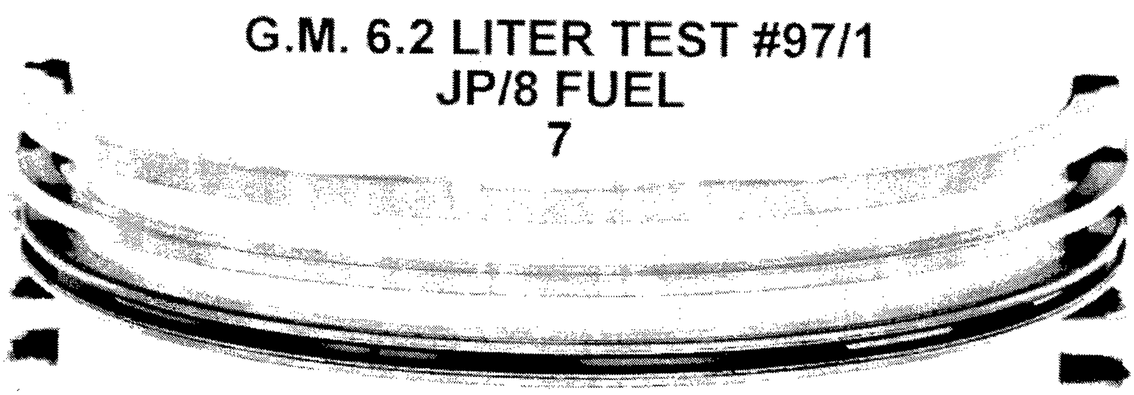


Figure A-25. <u>G.M. 6.2 Liter Test 97-1, JP-8 Fuel, Cylinder 7 Rings</u>

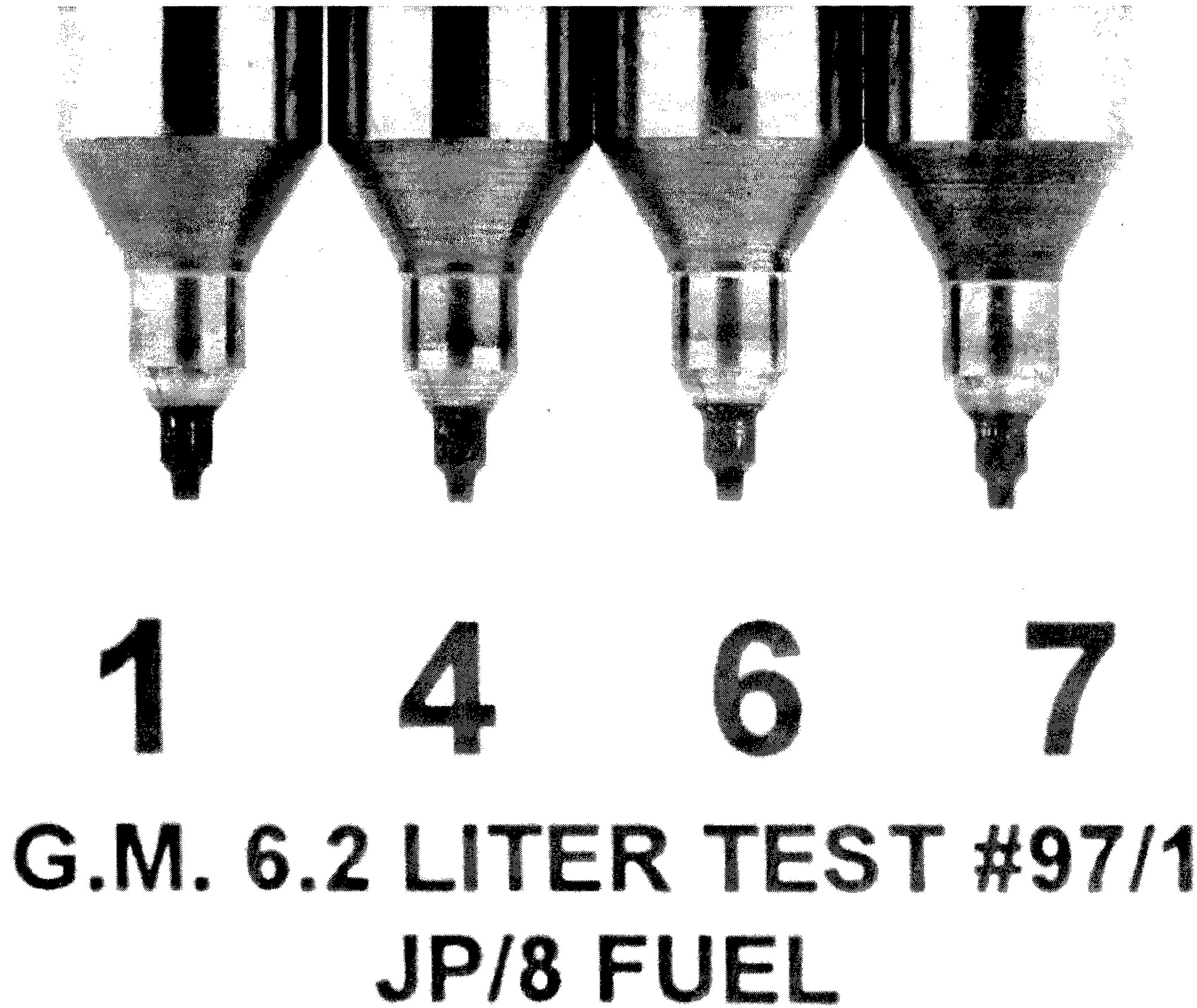


Figure A-26. G.M. 6.2 Liter Test 97-1, JP-8 Fuel, Injectors 1, 4, 6, and 7

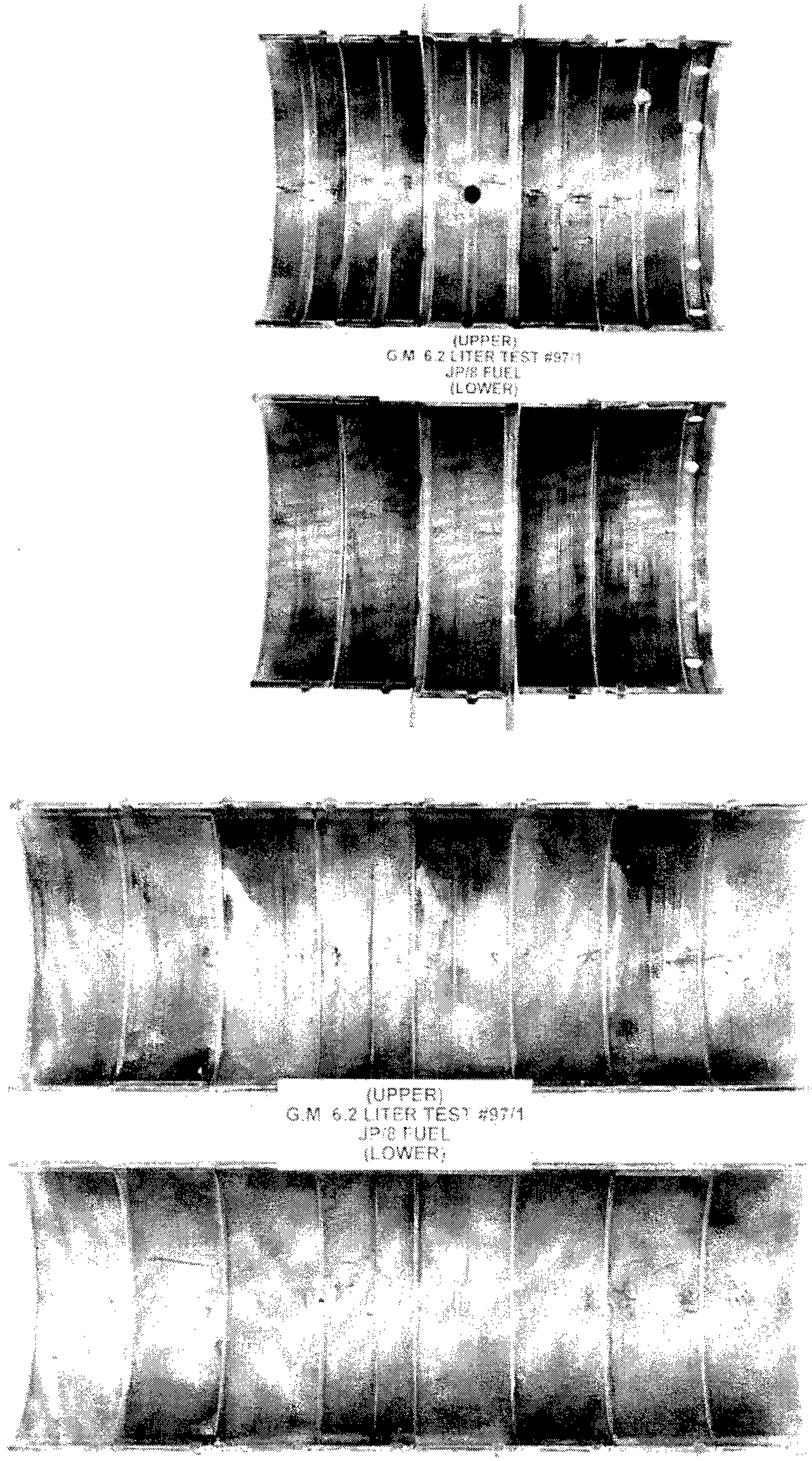


Figure A-27. **G.M. 6.2 Liter Test 97-1, JP-8 Fuel, Bearings (Upper and Lower)**

APPENDIX B
6.2L Blended JP-8/Used Oil Fuel Evaluation –Test 97-2

Evaluation of JP-8 Blended with Used Oil in a GM 6.2L Engine

Test Lubricant: AL-24610-L
Test Fuel: Blended JP-8 & Used Oil (AL-24855-F)
Test No.: 97-2
Date: June 1997

Conducted For

U.S. Army Tank-Automotive Research, Development and Engineering Center
Logistics Equipment Directorate
Fort Belvoir, Virginia 22060-5606

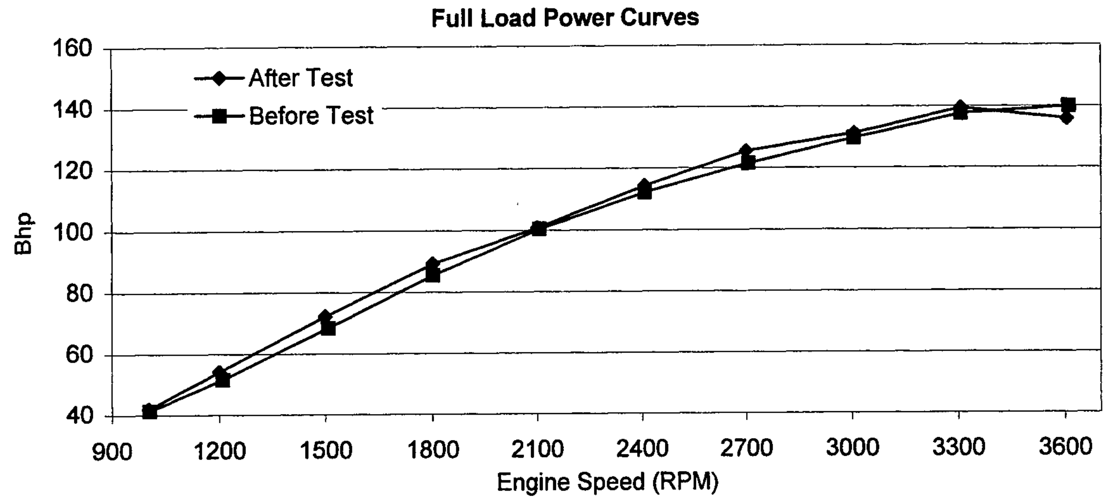
By

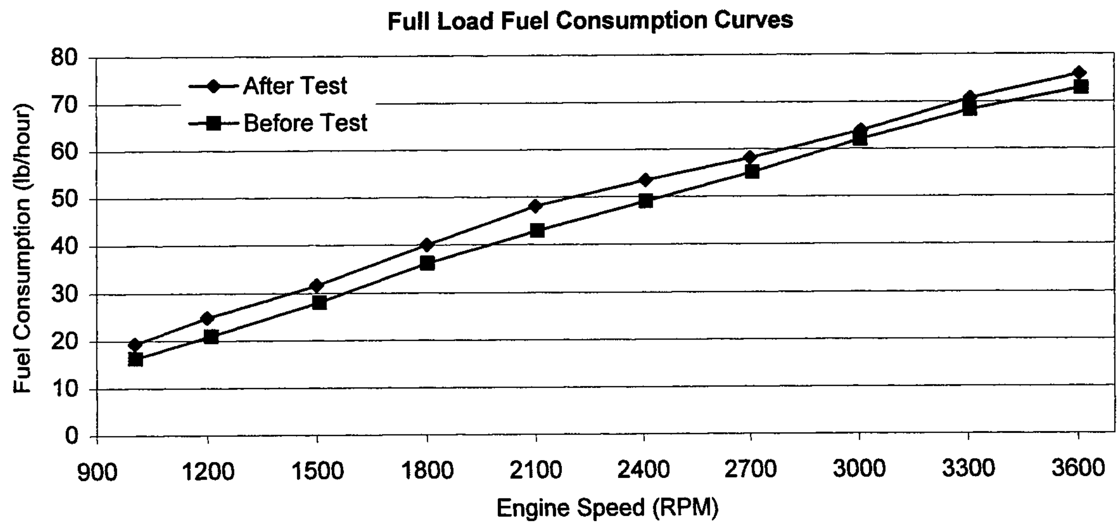
TARDEC Fuels and Lubricants Research Facility (SwRI)
Southwest Research Institute
P.O. Drawer 28510
San Antonio, Texas 78228-0510

GM 6.2L
97-2
ENGINE REBUILD MEASUREMENTS*
SERIAL NUMBER: 3GH2917

	Minimum	Maximum	Average	Specified Limits
Cylinder Block Bore				
Inside Diameter (Bottom)	3.9767	3.9977	3.9771	3.9759 - 3.9789
Out of Round	0.0001	0.0003	0.0002	0.0008 Max
Taper	0.0001	0.0002	0.0002	0.0008 Max
Piston Clearances				
Bores 1-6	0.0034	0.0042	0.0038	0.0035 - 0.0045
Bores 7-8	0.0039	0.0042	0.0040	0.0040 - 0.0050
Piston Ring Groove Clearance				
Second	0.0020	0.0020	0.0020	0.0015 - 0.0030
Oil	0.0020	0.0020	0.0020	0.0016 - 0.0038
Piston Ring End Gap				
Top	0.0190	0.0220	0.0200	0.012 - 0.022
Second	0.0330	0.0370	0.0350	0.029 - 0.039
Oil	0.0170	0.0190	0.0180	0.010 - 0.020
Piston Pin				
Diameter	1.2203	1.2205	1.2204	1.2203 - 1.2206
Clearance	0.0004	0.0006	0.0005	0.0004 - 0.0006
Fit in Rod	0.0005	0.0009	0.0007	0.0003 - 0.0012
Camshaft				
Diameter Bearings 1-4	2.1678	2.1679	2.1678	2.1678 - 2.1688
Diameter Bearing 5	n/a	n/a	2.0105	2.0099 - 2.0109
Clearance	0.0020	0.0024	0.0022	0.0015 - 0.0044
Crankshaft				
Journal Diameter 1-4	2.9498	2.9500	2.9499	2.9495 - 2.9504
Journal Diameter 5	n/a	n/a	2.9498	2.9493 - 2.9502
Out-of-Round	0.0000	0.0001	0.0000	0.0002 Max
Clearance 1-4	0.0021	0.0026	0.0024	0.0018 - 0.0033
Clearance 5	n/a	n/a	0.0028	0.0022 - 0.0031
Crankpin				
Diameter	2.3984	2.3988	2.3986	2.3981 - 2.3992
Out-of-Round	0.0000	0.0001	0.0000	0.0002 Max
Clearance	0.0027	0.0029	0.0028	0.0018 - 0.0039
Valves				
Stem Clearance - Intake	0.0018	0.0028	0.0023	0.001 - 0.0027
Stem Clearance - Exhaust	0.0016	0.0027	0.0022	0.001 - 0.0027

* Note: Measurements are in inches





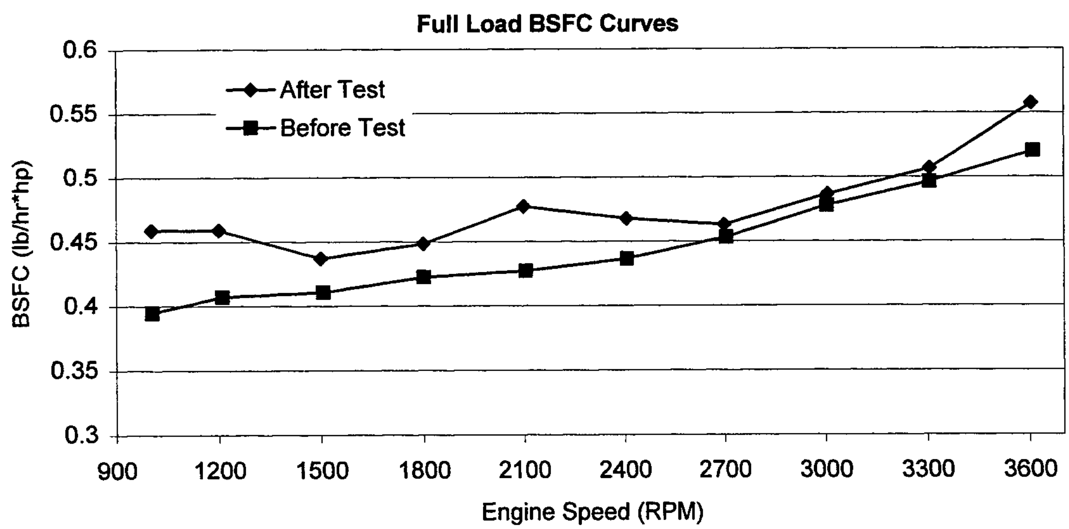


Figure B-1. Full Load Performance

GM 6.2L
97-2
Operating Conditions Summary
Serial Number: 3GH2917

	Maximum Power Mode (3600 RPM)		Idle Mode (800 RPM)	
	Mean	Standard Deviation	Mean	Standard Deviation
Engine Speed, rpm	3604	6	913	11
Torque, ft-lb	209	11	18	4
Fuel Consumption, lb/hr	74.9	0.9	4	0.7
Observed Power, Bhp	144	8	3	1
BSFC, lb/Bhp-hr	0.52	0.03	1.36	0.45
Oil Gallery pressure, psi	57	3	50	2
Temperatures, °F				
Water Jacket Inlet	158	2	159	9
Water Jacket Outlet	179	1	180	8
Oil Sump	236	11	232	8
Fuel Inlet	96	3	95	4
Air Inlet	89	6	87	5
Exhaust Temperatures, °F				
Cylinder 1	1147	15	221	10
Cylinder 2	1150	15	222	10
Cylinder 3	1201	25	212	11
Cylinder 4	1173	32	250	73
Cylinder 5	1181	39	197	29
Cylinder 6	1123	113	229	15
Cylinder 7	1170	27	229	11
Cylinder 8	1187	22	211	32
Common	1147	20	190	13

GM 6.2L
97-2
BLENDED FUEL ANALYSIS
Fuel: AL-24855-F*

Property		ASTM Method	AL-24647-F	AL-24855-F
Gravity at 60°F		D 287	43.2	
Distillation, °C	IBP	D 86	153	
	10%	D 86	174	
	30%	D 86	190	
	50%	D 86	206	
	70%	D 86	225	
	80%	D 86	237	
	90%	D 86	266	
	End Point	D 86	287	
	Recovered, vol%	D 86	93.9	
	Residue, vol%	D 86	6.1	
Flash Point, °C		D 92	43	
Cloud Point, °C		D 5773	Not obtainable	
Cetane Number		D 613	46.2	
Kinematic Viscosity at 40°C, cSt		D 445	1.6	
Cu Corrosion, at 100°C		D 130	lb	
Total Acid Number		D 664	0.22	
Aromatics, vol%		D 1319	17.5+	
Sulfur, mass%		D 2622	0.08	
Net Heat of Combustion, Btu/lb (MJ/kg)		D 240	18,578 (43.21)	
Carbon, mass%		D 5291	85.81	
Hydrogen, wt%		D 5291	13.72	
Particulate Contamination, mg/L		D 5452	14.2*	
Existent Gum, mg/100 mL		D 381	3146.7	
Carbon Residue (10% Bottoms)		D 524	1.07	
Ash, wt%		D 482	0.064	
Accelerated Stability, mg/100mL		D 2274	0.2**	
Interfacial Tension, dynes/cm		D 971	20.8	
Lubricity:	HFRR, mm	ISO	0.46	
	BOCLE, mm	D 5001	0.71	
	SLWT, kg	ARMY	4150++	
Water Content, ppm		D 4928	384	
Elemental, ppm	Ca	D 5185	143	163
	Mg	D 5185	17	19
	P	D 5185	62	66
	Zn	D 5185	81	88
	Ag	D 5185	<1	
	Al	D 5185	1	
	B	D 5185	6	
	Ba	D 5185	<1	
	Cr	D 5185	1	
	Cu	D 5185	6	
	Fe	D 5185	8	
	Mo	D 5185	6	
	Mn	D 5185	<1	
	Ni	D 5185	<1	
	Pb	D 5185	<1	
	Sb	D 5185	<1	
	Si	D 5185	3	
	Sn	D 5185	<1	
	Na	D 5185	4	

* Most of the analysis was performed using AL-24647-F, a typical JP-8 fuel blended with 7.5% used oil. Al-24855-F was tested for several wear metals to confirm that the blend is similar to AL-24647-F.

** Soot is visible on both the control and test filters

+ Soot came down column and olefin and aromatic separation was not definitive

++ Increased chatter during non-scuffing

GM 6.2L
97-2
ANALYSIS OF USED OIL FOR FUEL BLEND*
Composite Used Oil: AL-24627-L and AL-24644-L

Property		ASTM Method	AL-24627-L	AL-24644-L**
Viscosity at 40°C, cSt		D 445	82.19	82.19
Flash Point, °C		D 92	207	ND***
Tan		D 664	2.51	ND
Water Content, ppm		D 4928	1910	1760
Pentane Insoluables, wt%		D 893B	0.04	0.05
Toluene Insoluables, wt%		D 893B	0.03	0.04
Gravity at 60°F		D 287	27.8	27.8
Sulfur, wt%		X-Ray	0.6	0.6
Chlorine, ppm		X-Ray	<200	<200
Soot, wt%		TGA	0.5	0.5
Sulfated Ash, wt%		D 874	0.89	ND
Elemental, ppm	Ca	D 5185	1933	1947
	Mg	D 5185	212	210
	P	D 5185	8.78	879
	Zn	D 5185	1004	1013
	Ag	D 5185	<1	<1
	Al	D 5185	12	12
	B	D 5185	85	86
	Ba	D 5185	3	3
	Cr	D 5185	10	10
	Cu	D 5185	67	67
	Fe	D 5185	96	95
	Mo	D 5185	75	75
	Mn	D 5185	3	3
	Ni	D 5185	3	3
	Pb	D 5185	20	21
	Sb	D 5185	<1	<1
	Si	D 5185	45	45
	Sn	D 5185	8	8
	Na	D 5185	15	15

* Analysis was performed on used oil taken from vehicles at Ft. Hood, TX (Letter Report No. TFLRF-97-001)
** Oil was filtered (25 micron Fleetguard FF-202 fuel filter) prior to analysis.
*** ND = Not Determined

GM 6.2L
97-2
LUBRICANT ANALYSIS
Lubricant: AL-24610-L

	ASTM Test Method	Test Time, Hours 0	70	140	154	210
Kinematic Viscosity at 40°C (104°F) cSt	D 445	108.64	118.61	162.37	165.76	121.3
Kinematic Viscosity at 100°C (212°F) cSt	D 445	14.46	13.27	16.23	16.52	13.74
Total Acid Number mg KOH/g	D 664	1.48	5.55	6.52	6.62	5.06
Total Base Number mg KOH/g	D 4739	5.48	2.09	3.01	0.91	2.05

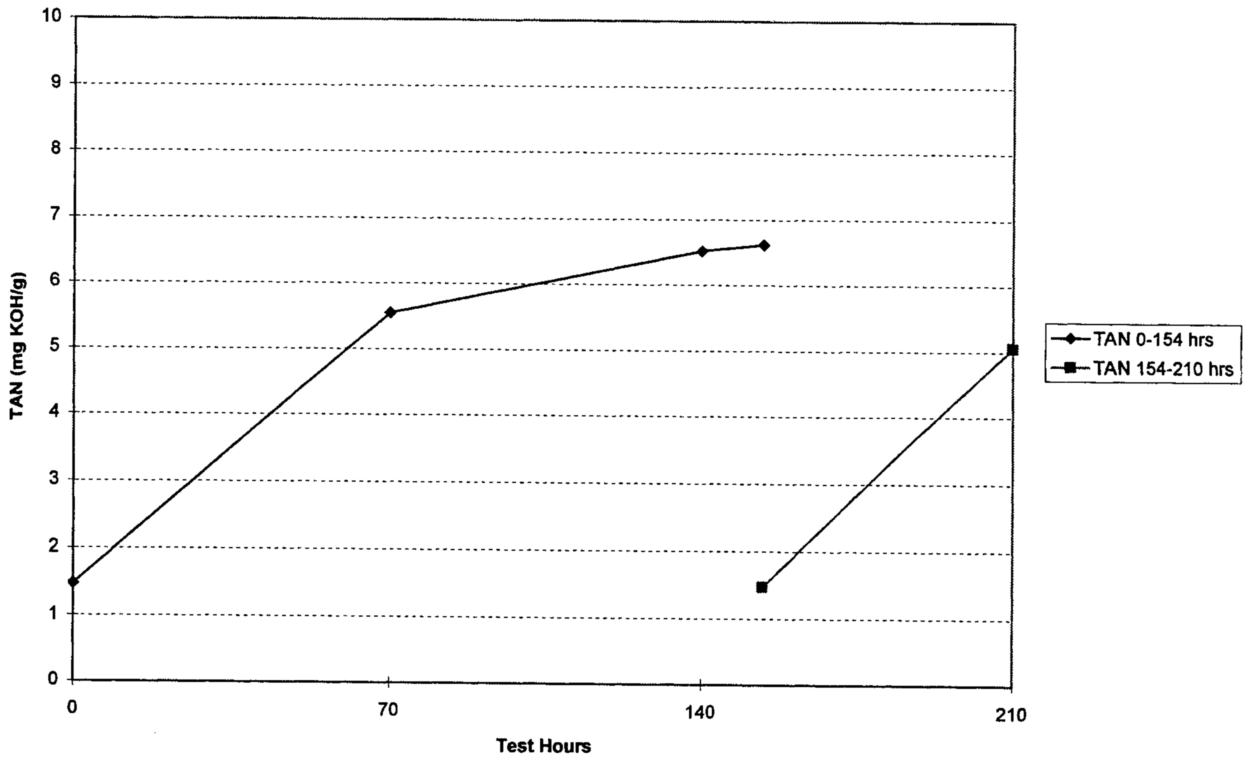


Figure B-2. **GM 6.2L Test 97-2 Total Acid Number**

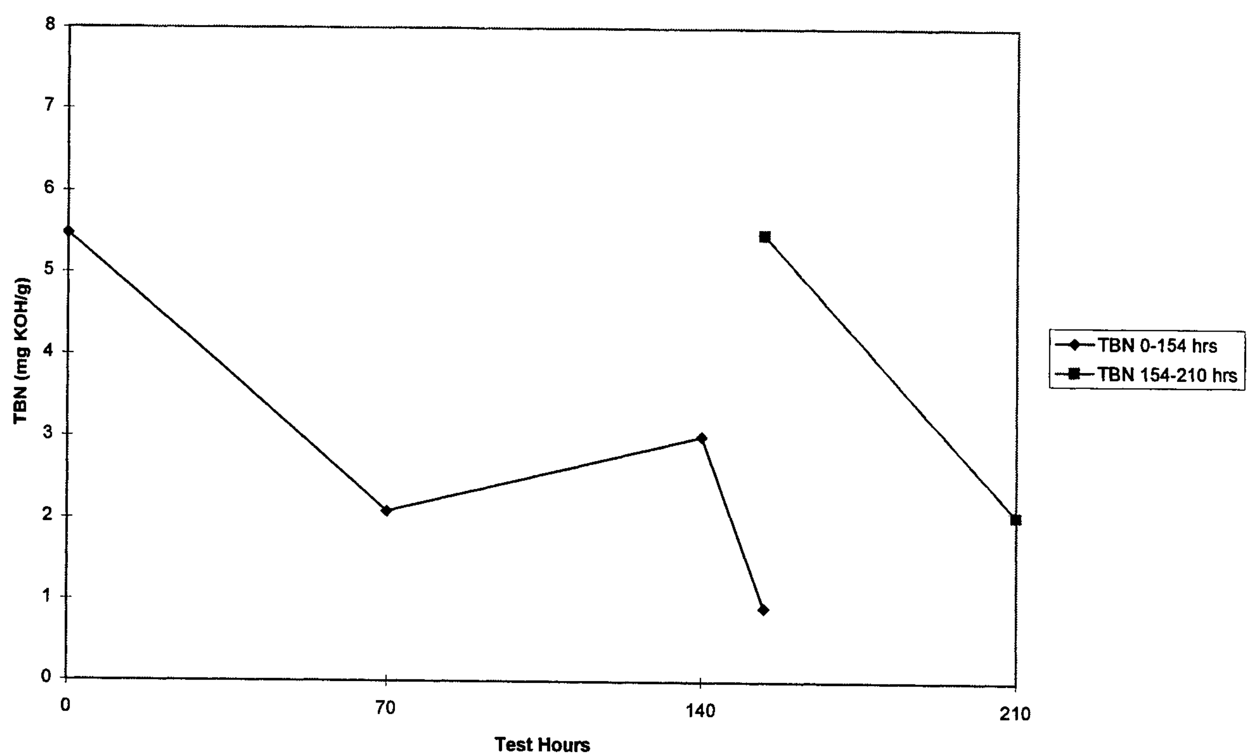


Figure B-3. **GM 6.2L Test 97-2 Total Base Number**

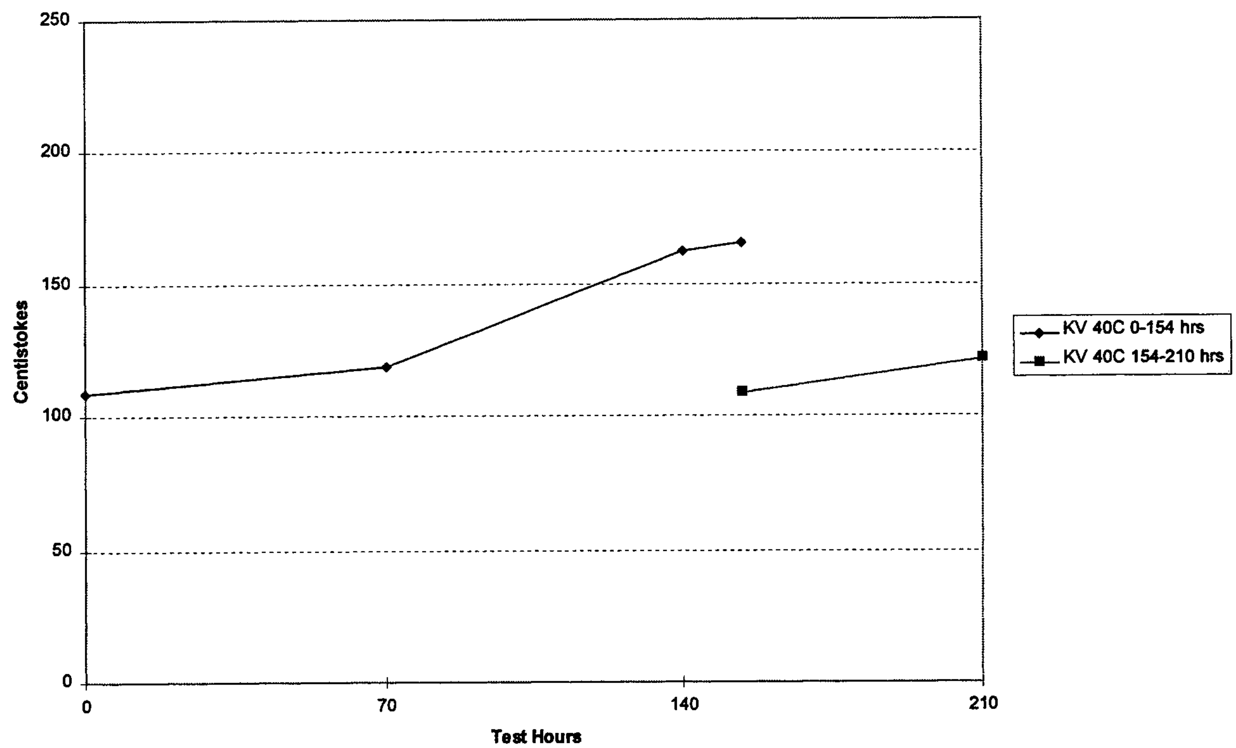


Figure B-4. **Kinematic Viscosity at 40°C**

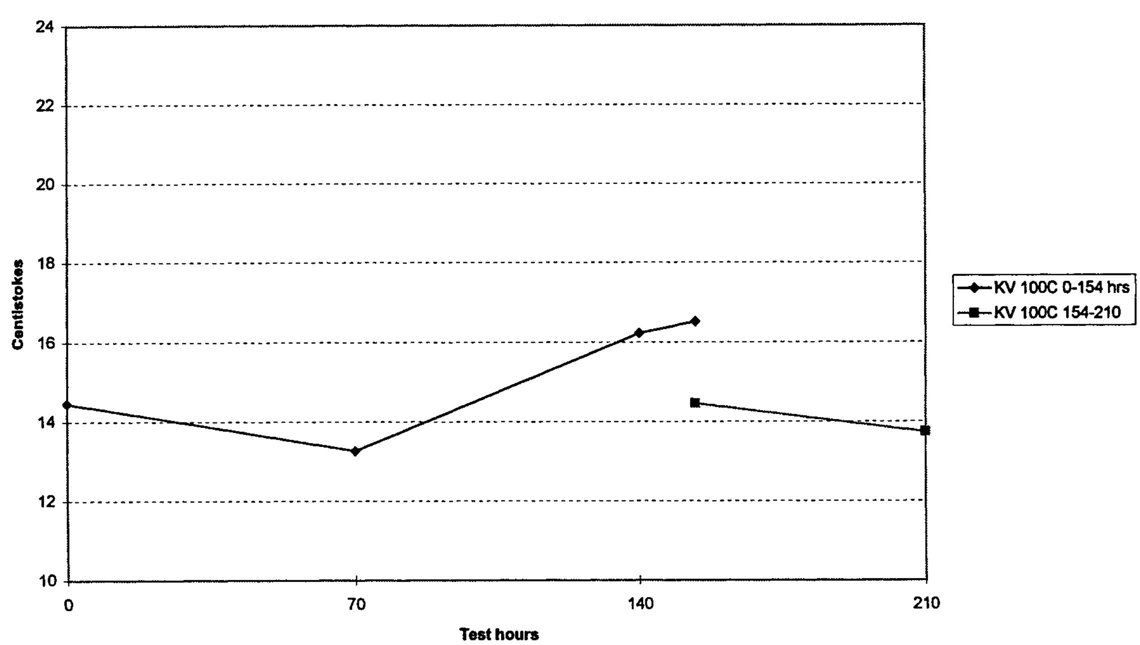


Figure B-5. **Kinematic Viscosity at 100°C**

GM 6.2L
97-2
TOTAL CONSUMPTION AND WEAR METALS BY XRF
Lubricant: AL-24610-L

Test Time, Hours	Total Oil Consumed, lb	Wear Metals, ppm Fe	Cu	Pb
0	0	6	9	5
Break-in		35	60	37
14	0.89	33	25	13
28	1.09	58	38	25
42	1.37	87	46	40
56	1.02	112	67	49
70	1.30	142	98	62
84	1.22	175	142	75
98	1.13	194	186	77
112	1.20	217	229	87
126	1.20	244	262	102
140	2.00	269	305	112
154	2.27	279	280	116
168	0.26	92	101	28
182	1.08	133	115	35
196	1.42	164	111	50
210	0.78	187	134	64

Total oil consumed: 18.22 lb
Average oil consumption rate: 0.087 lb/hr

Note: Oil was changed at 154 hours
* X-ray fluorescence spectroscopy

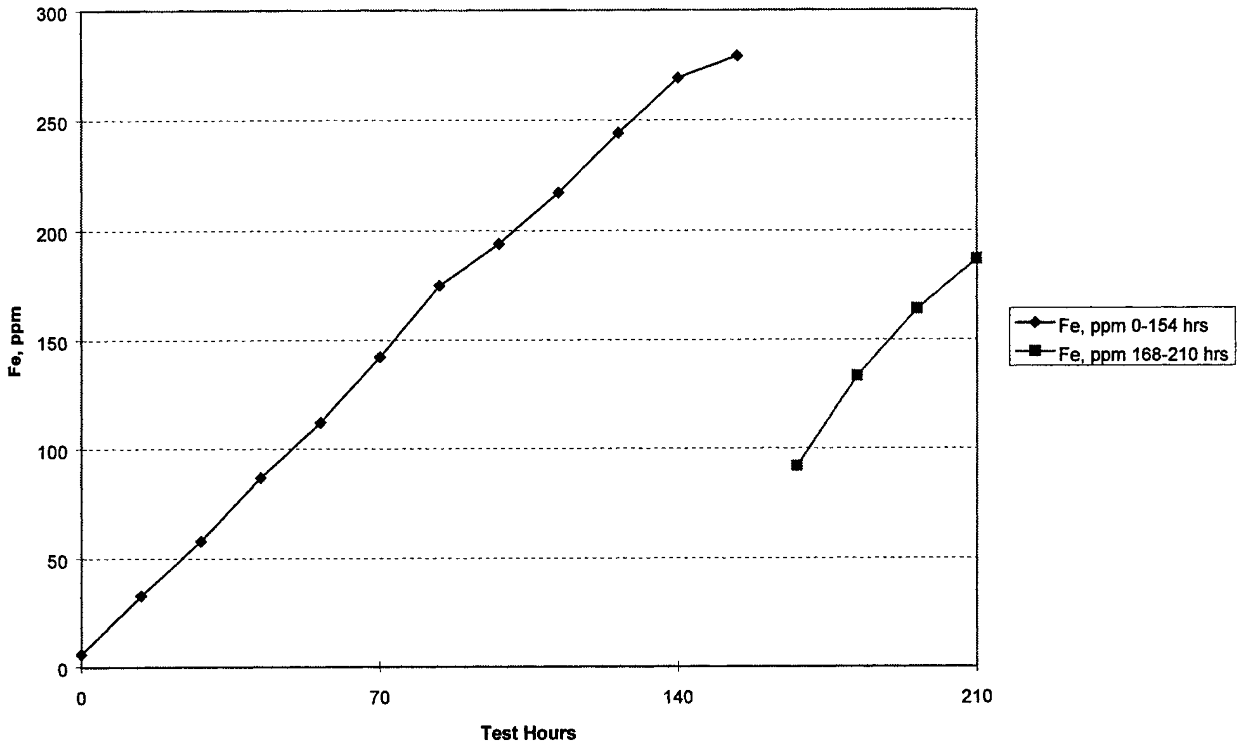


Figure B-6. **<u>Test 97-2 Iron Wear Metal</u>**

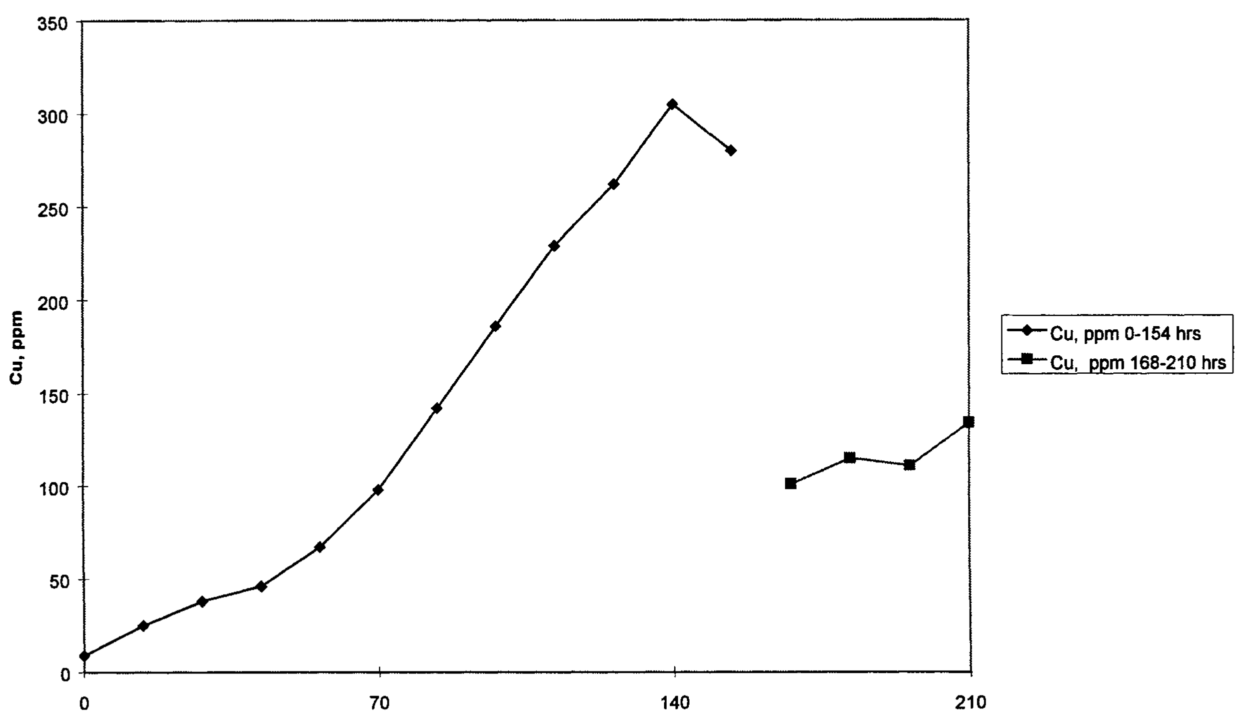


Figure B-7. **<u>Copper Wear Metal</u>**

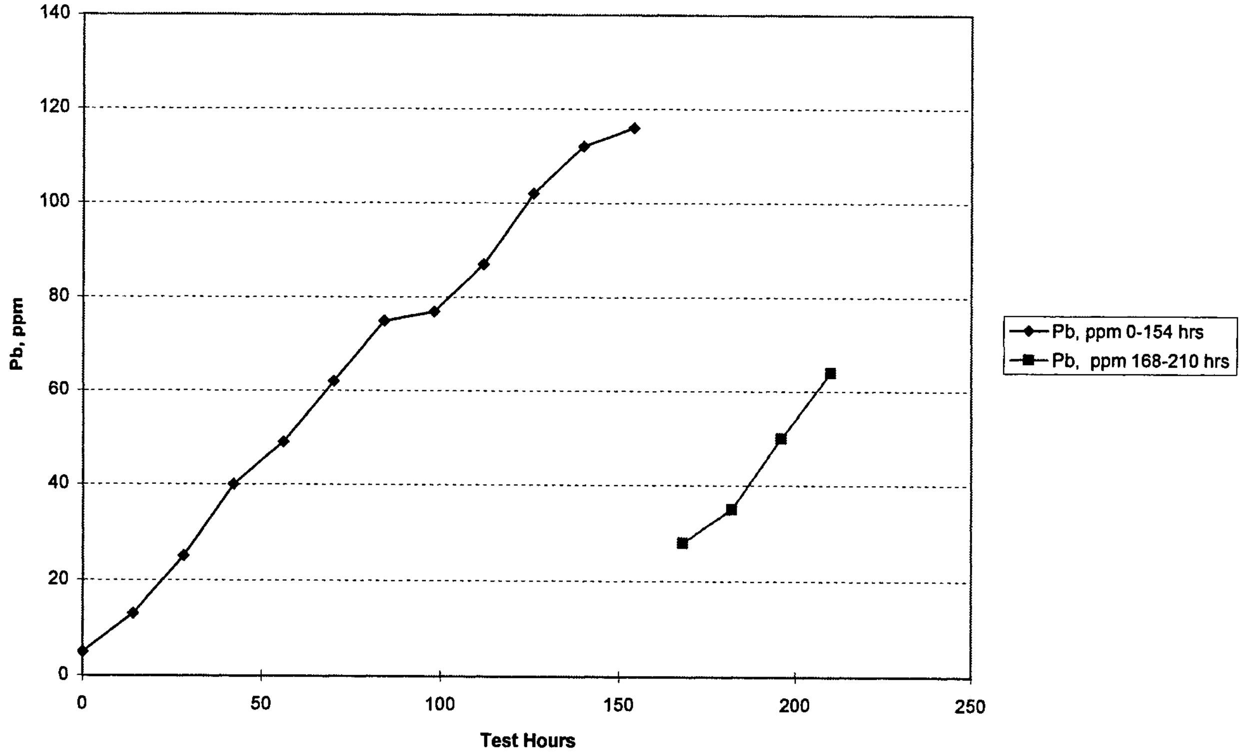


Figure B-8. Lead Wear Metal

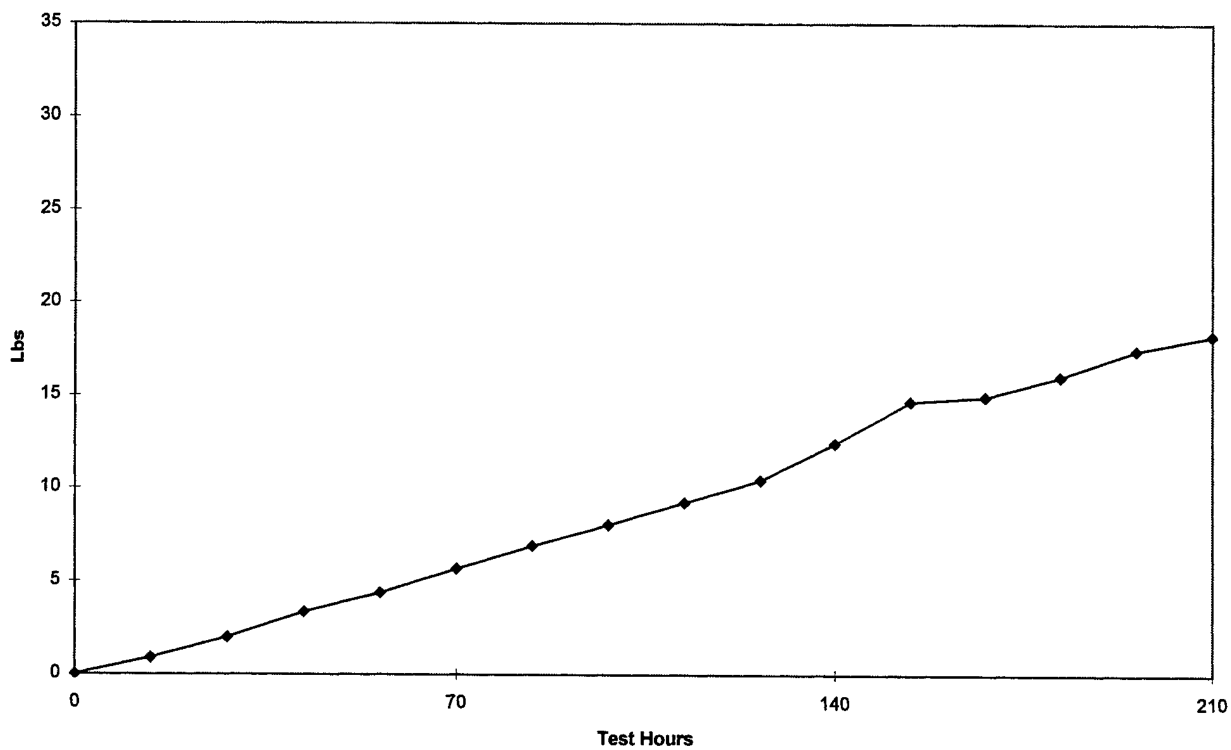


Figure B-9. Cumulative Oil Consumption

GM 6.2L
97-2
WEAR MEASUREMENTS*
Lubricant: AL-24610-L

Cylinder Liner Bore Diameter Change

	1		3		5		7	
	T-AT**	F-B	T-AT	F-B	T-AT	F-B	T-AT	F-B
Top	0.0003	0.0001	0.0002	0.0001	0.0003	0	0.0003	0.0001
Middle	0.0001	0.0002	0.0000	0.0001	0.0001	0.0001	0.0001	0.0001
Bottom	0.0002	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

	2		4		6		8	
	T-AT	F-B	T-AT	F-B	T-AT	F-B	T-AT	F-B
Top	0.0027	0.0000	0.0003	0.0000	0.0003	0.0001	0.0001	0.0000
Middle	0.0003	0.0000	0.0002	0.0000	0.0002	0.0001	0.0000	0.0001
Bottom	0.0001	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001	0.0000

Average Change

	T-AT	F-B
Top	0.000563	0.00005
Middle	0.000125	0.00009
Bottom	0.000075	0.00003

Overall cverage change: 0.00015

Piston Ring End Gap Change

Ring	1	2	3	4	5	6	7	8	Average
Top	0.010	0.011	0.004	0.013	0.011	0.008	0.005	0.002	0.008
Second	0.002	0.002	0.001	0.003	0.001	0.006	0.000	0.000	0.002
Oil	0.003	0.004	0.009	0.008	0.005	0.006	0.002	0.004	0.005

Overall average change: 0.005

Keystone Top Ring Proudness

1	2	3	4	5	6	7	8	Average
0.008	0.008	0.009	0.007	0.008	0.009	0.009	0.011	0.0086

Bearing Weight Change, g

Main Bearings	1	2	3	4	5	Average
Upper	0.1654	0.1208	0.0374	0.0686	0.0975	0.0979
Lower	0.2350	0.5821	0.1550	0.1137	0.1105	0.2393

Overall average change: 0.1686

Rod Bearings	1	2	3	4	5	6	7	8	Average
Upper	0.2731	0.1251	0.1429	0.0817	0.0919	0.0964	0.1096	0.0933	0.1268
Lower	0.0620	0.0448	0.0438	0.0334	0.0264	0.0339	0.0403	0.0337	0.0398

Overall average change: 0.0833

Valve Recession

Valve	1	2	3	4	5	6	7	8	Average
Intake	0.0047	0.0079	0.0074	0.0012	0.0071	0.0018	0.0082	0.0026	0.0053
Exhaust	0.0029	0.0072	0.0018	0.0034	0.0028	0.0015	0.0057	0.0064	0.0038

Overall average change: 0.0045

*All dimensions are given in inches.
**T-AT=Thrust-Antithrust Direction; F-B= Front-Back Direction.

GM 6.2L
97-2
POST TEST ENGINE CONDITION AND DEPOSITS
Lubricant: AL-24610-L

	Cylinder Number								
	1	2	3	4	5	6	7	8	Average
Cylinder Liner									
Liner Scuffing,% Area									
%Total Area Scuffing	0	0	1	0	1	0	0	0	0.25
Thrust	0	0	0	0	0	0	0	0	0.00
Anti-Thrust	0	0	1	0	1	0	0	0	0.25
Pistons									
Top Groove Fill, %	23	55	38	72	84	89	99	100	70.0
Int. Groove Fill, %	2	5	7	4	6	8	8	22	7.8
Weighted Deposit, 1K	177.6	276.6	368.4	375.3	359.5	438.8	407.0	429.9	354.1
Ring Condition	Good	Good	Good	Good	Good	Good	Good	Good	
Valves									
Intake	7.0	6.8	6.7	6.8	6.7	6.6	6.5	6.6	6.7
Exhaust	8.7	8.7	8.5	8.9	8.7	8.7	8.7	8.5	8.7
Combustion Chamber Deposits									
Merit Rating	7.00	6.78	7.20	6.92	7.30	6.92	6.80	6.75	6.96
Prechamber Deposits, g									
Bearing Surface*									
Main Bearings, % Wear, %Scratched, Pitting									
Upper	50%LS	5%LS	0%LS	10%LS	3%LS				
Lower	70%LS	70%LS	2%LS	20%LS	15%LS				
Rod Bearing, % Wear, % Scratched, Pitting									
Upper	70%MS	5%LS	5%LS	2%LS	2%LS	2%LS	2%LS	2%LS	
Lower	30%LS	10%LS	10%LS	2%LS	2%LS	2%LS	2%LS	2%LS	

* LS = Light Scratching, MS = Medium Scratching

GM 6.2L
Test 97-2
FUEL INJECTOR TESTS
Fuel: AL-24855-F

	Cylinder Number								
	1	2	3	4	5	6	7	8	Average
Pop-Off Pressure, Psi (1500 min)									
Before Test	1900	1850	1875	1850	1875	1875	1850	1850	1866
After Test	1700	1675	1675	1700	1675	1675	1650	1650	1675
Leak Back Time, Seconds (10 min)									
Before Test	15	21	11	23	14	21	26	15	18
After Test	9	9	6	10	7	10	12	8	9
Fuel Pump Calibration									
(cc / 1000 strokes) @ 1000 RPM									
Before Test	49								
After Test	53								
Overall Change	4								
(cc / 1000 strokes) @ 1800 RPM									
Before Test	90								
After Test	90								
Overall Change	0								

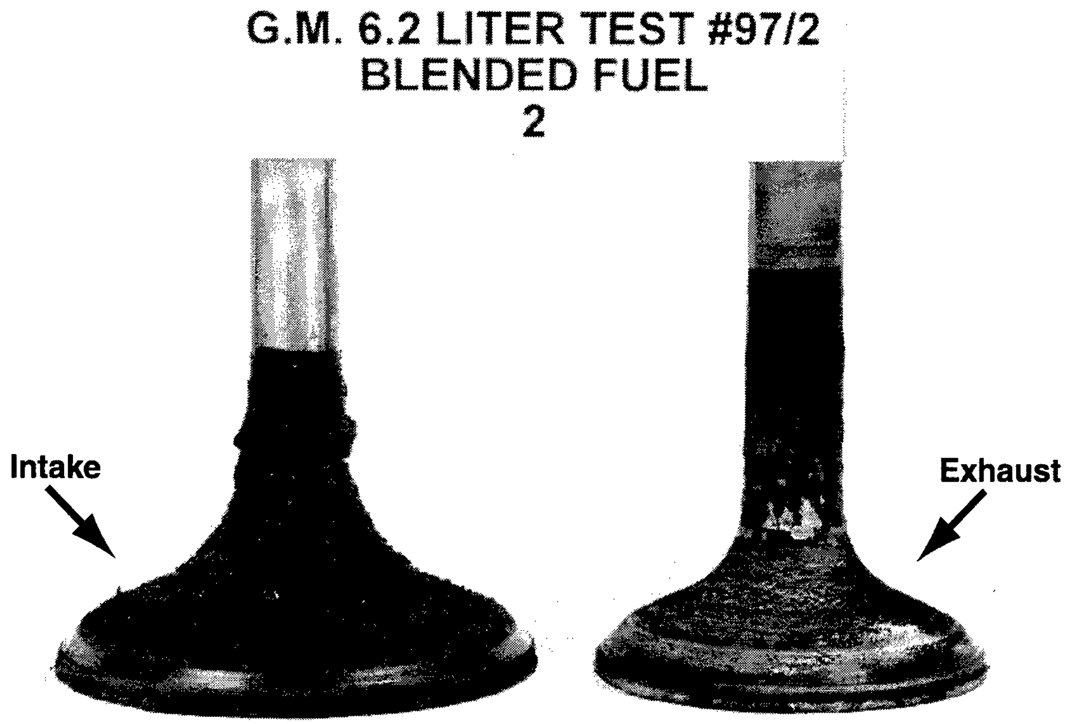


Figure B-10. G.M. 6.2 Liter Test #97/2, Blended Fuel, Cylinder 1 Valves

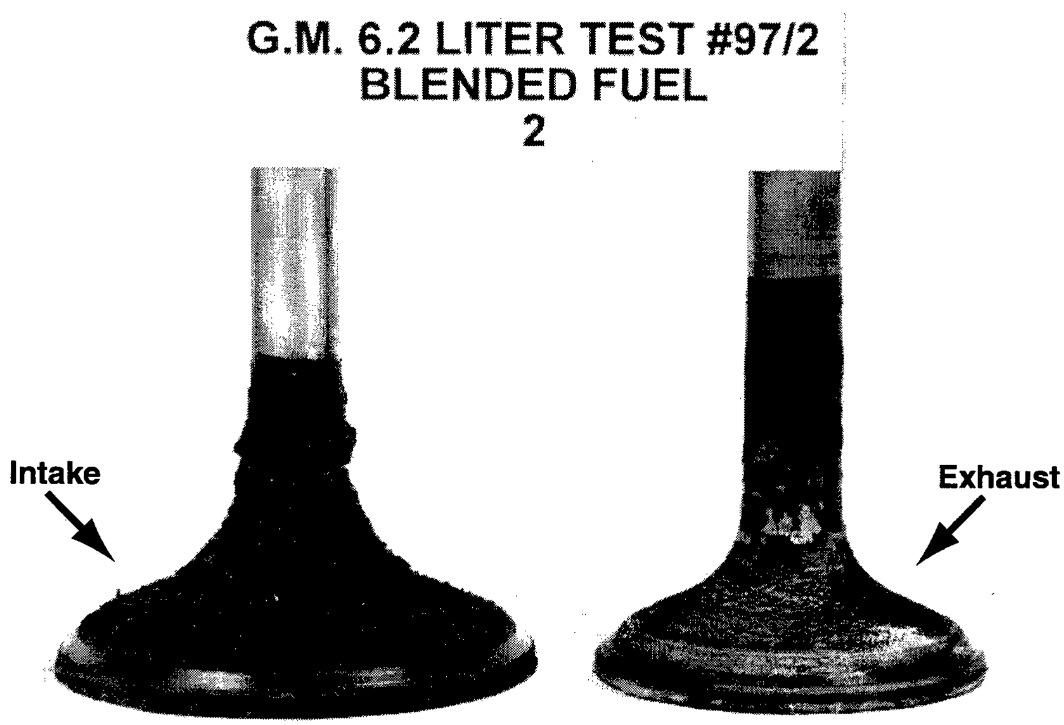


Figure B-11. G.M. 6.2 Liter Test #97/2, Blended Fuel, Cylinder 2 Valves

Figure B-12. G.M. 6.2 Liter Test #97/2, BLended Fuel, Cylinder 3 Valves

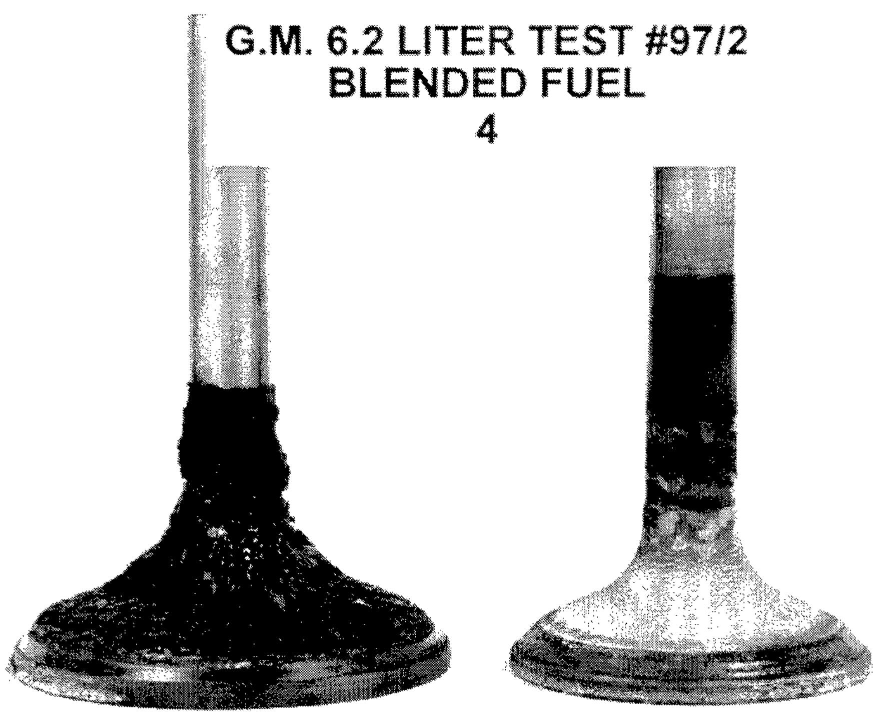


Figure B-13. G.M. 6.2 Liter Test #97/2, Blended Fuel, Cylinder 4 Valves

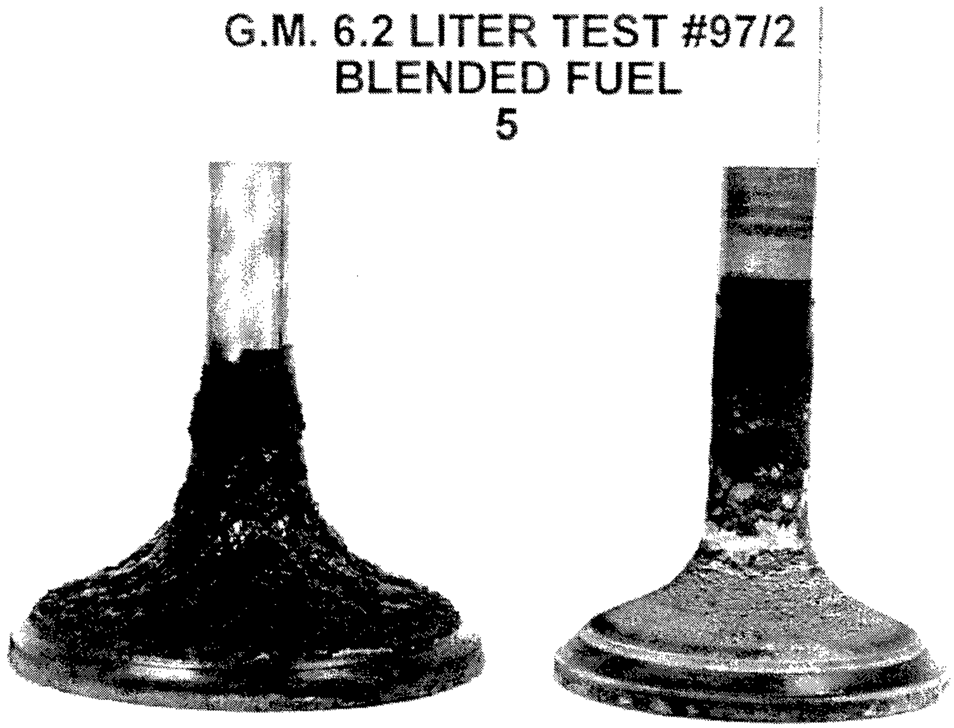


Figure B-14. G.M. 6.2 Liter Test #97/2, Blended Fuel, Cylinder 5 Valves

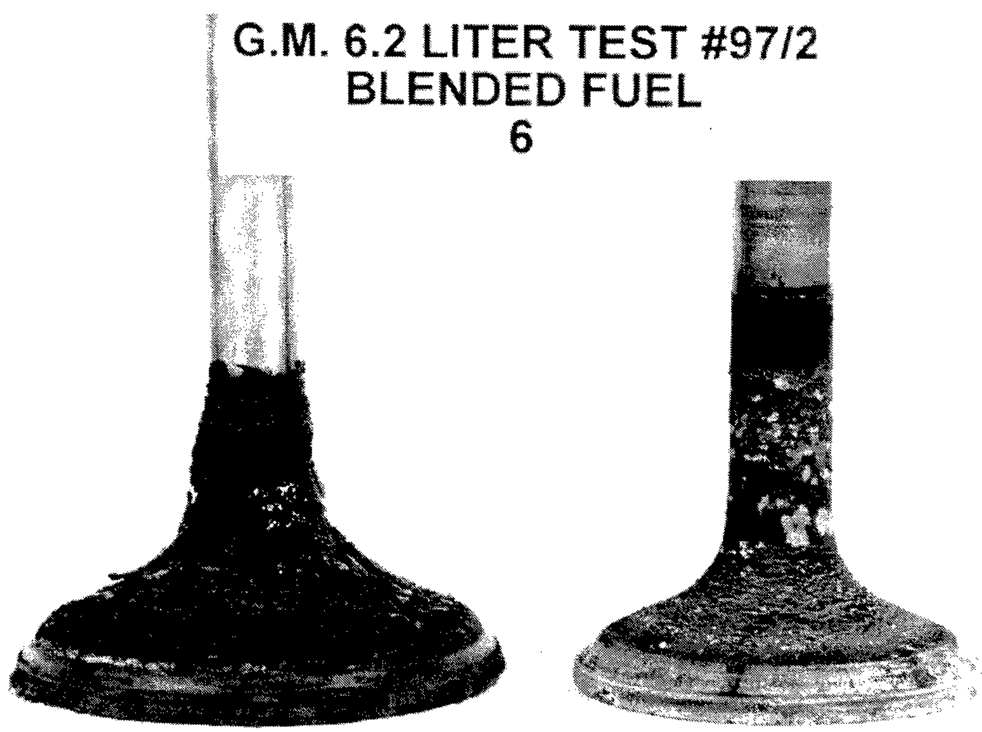


Figure B-15. G.M. 6.2 Liter Test #97/2, Blended Fuel, Cylinder 6 Valves

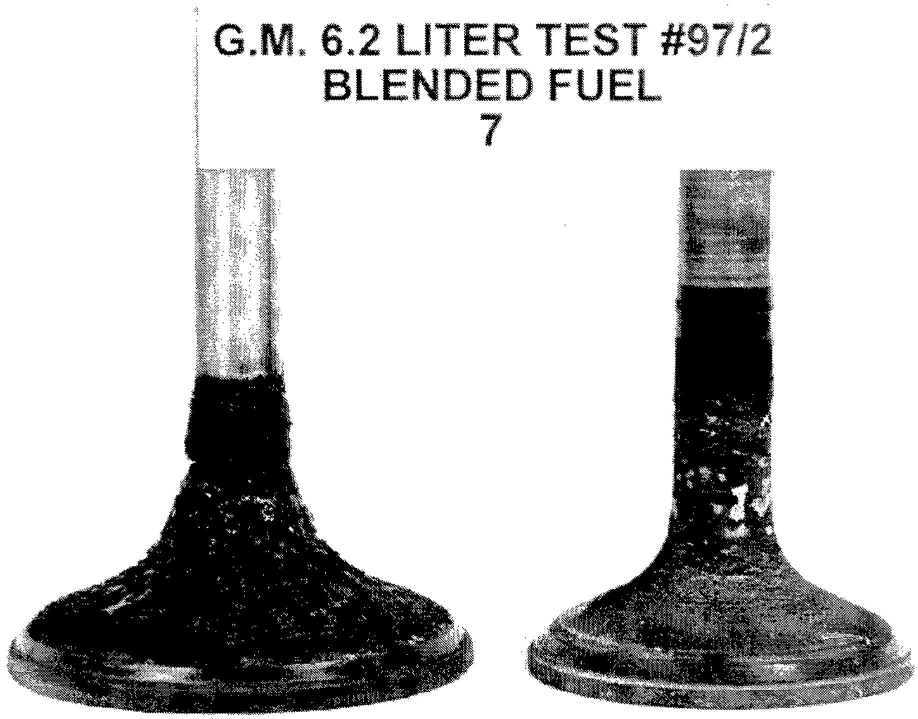


Figure B-16. **<u>G.M. 6.2 Liter Test #97/2, BLended Fuel, Cylinder 7 Valves</u>**

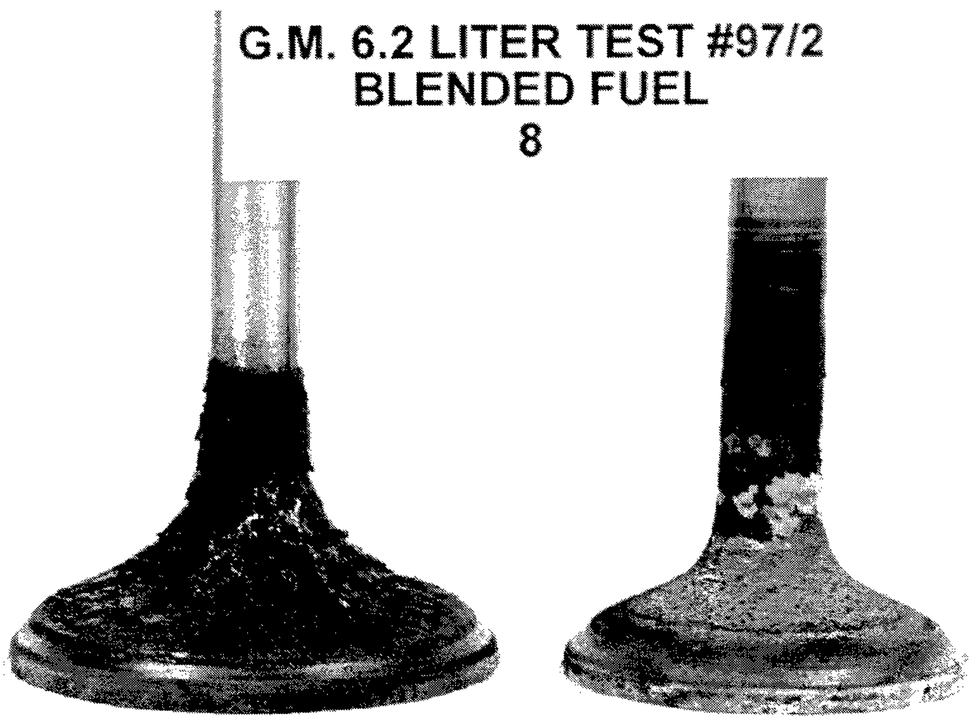


Figure B-17. **<u>G.M. 6.2 Liter Test #97/2, Blended Fuel, Cylinder 8 Valves</u>**

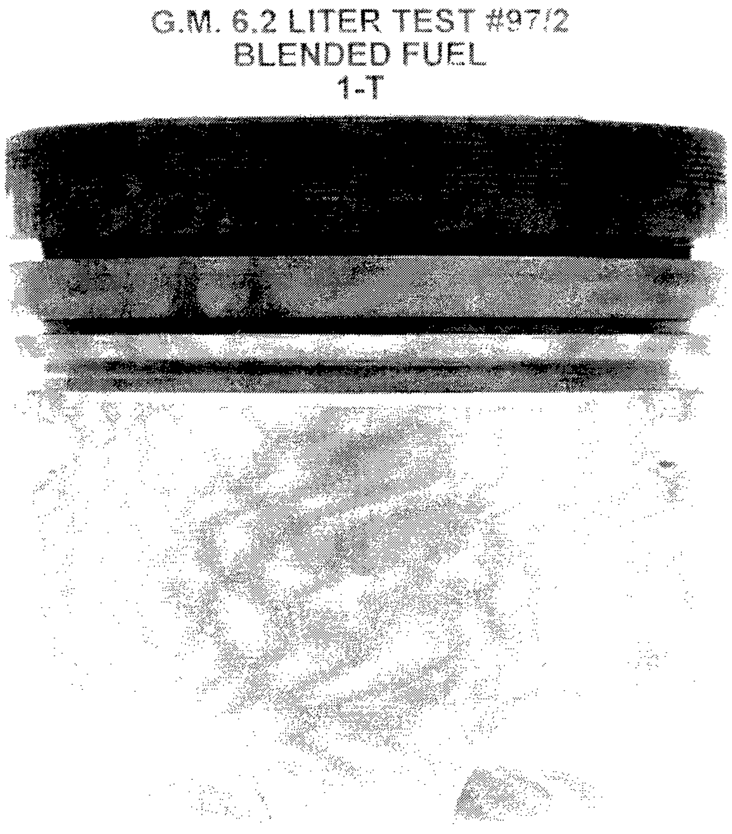


Figure B-18. G.M. 6.2 Liter Test 97-2, Blended Fuel, Piston 1-T

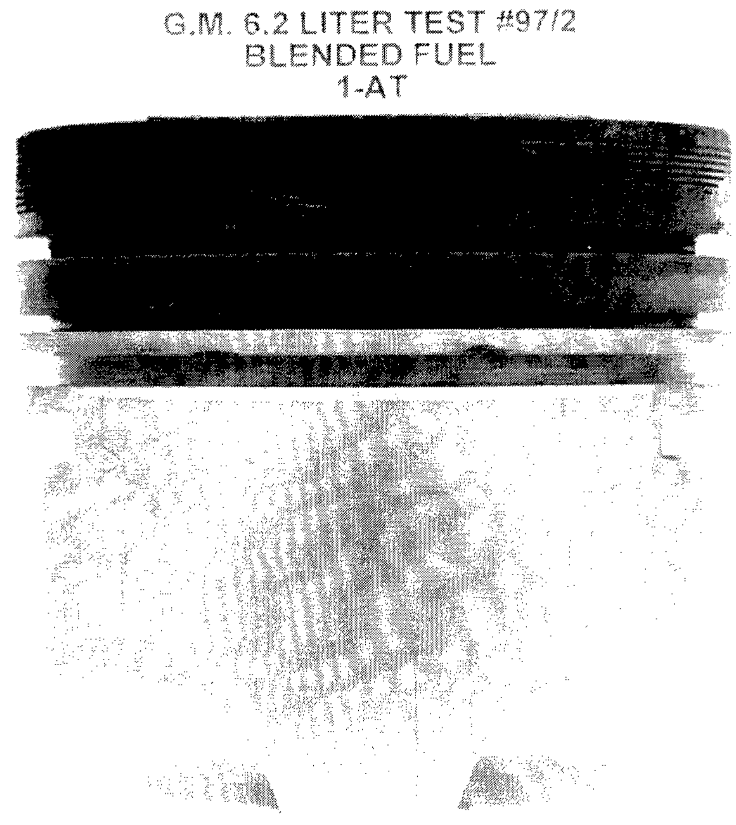


Figure B-19. G.M. 6.2 Liter Test 97-2, Blended Fuel, Piston 1-AT

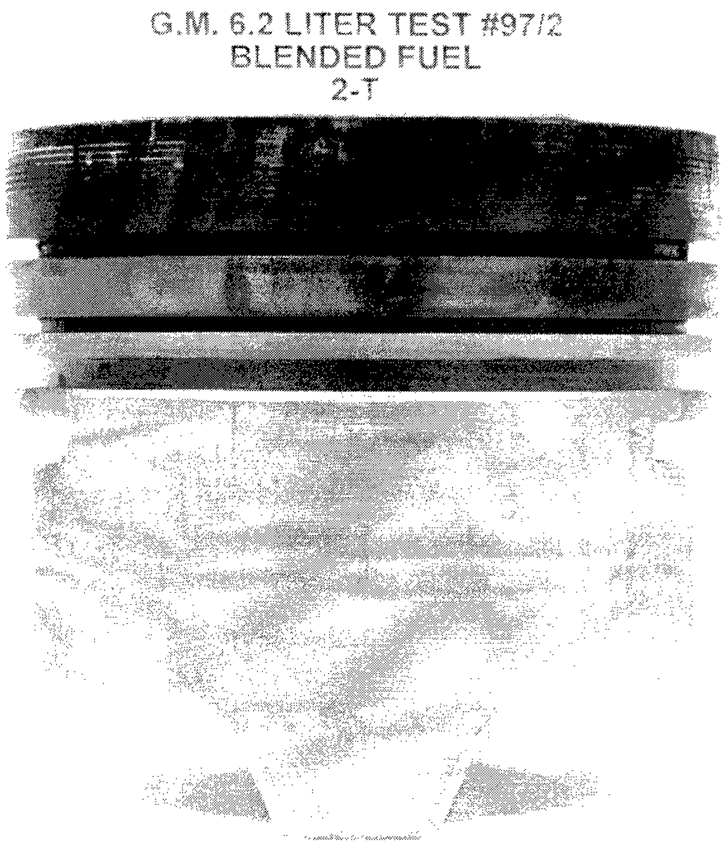


Figure B-20. G.M. 6.2 Liter Test 97-2, Blended Fuel, Piston 2-T

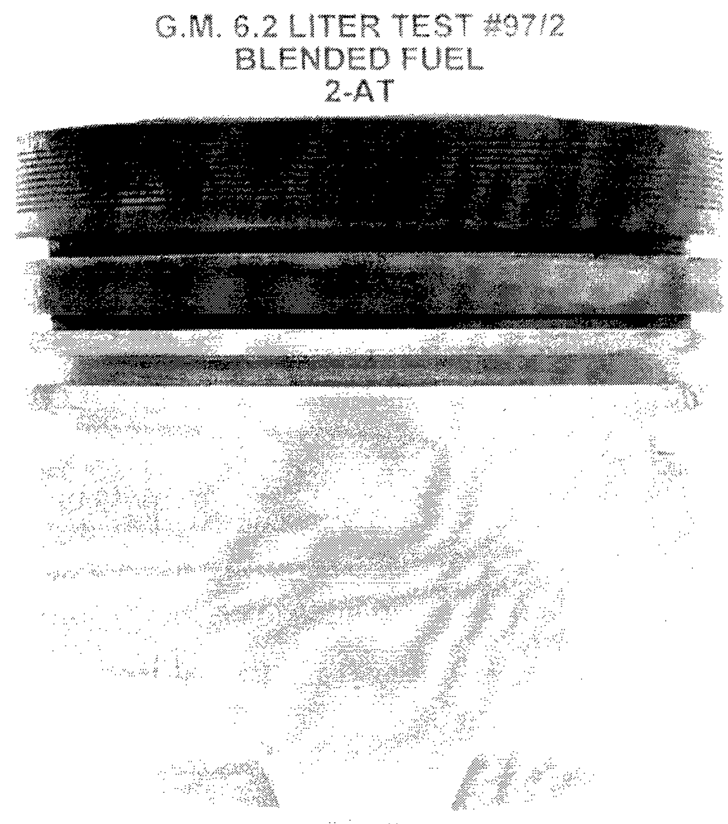


Figure B-21. G.M. 6.2 Liter Test 97-2, Blended Fuel, Piston 2-AT

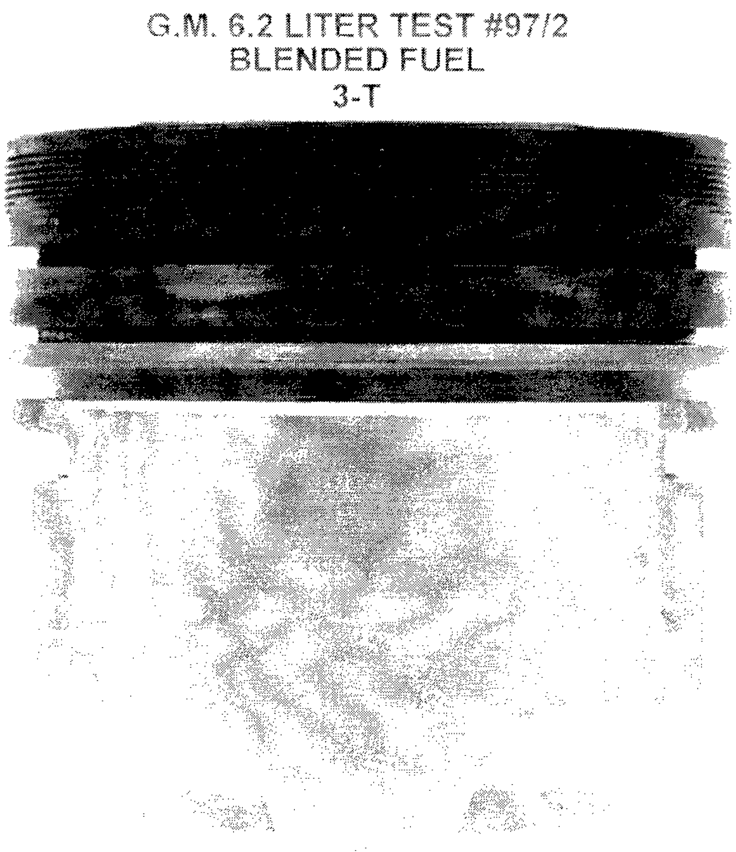


Figure B-22. G.M. 6.2 Liter Test 97-2, Blended Fuel, Piston 3-T

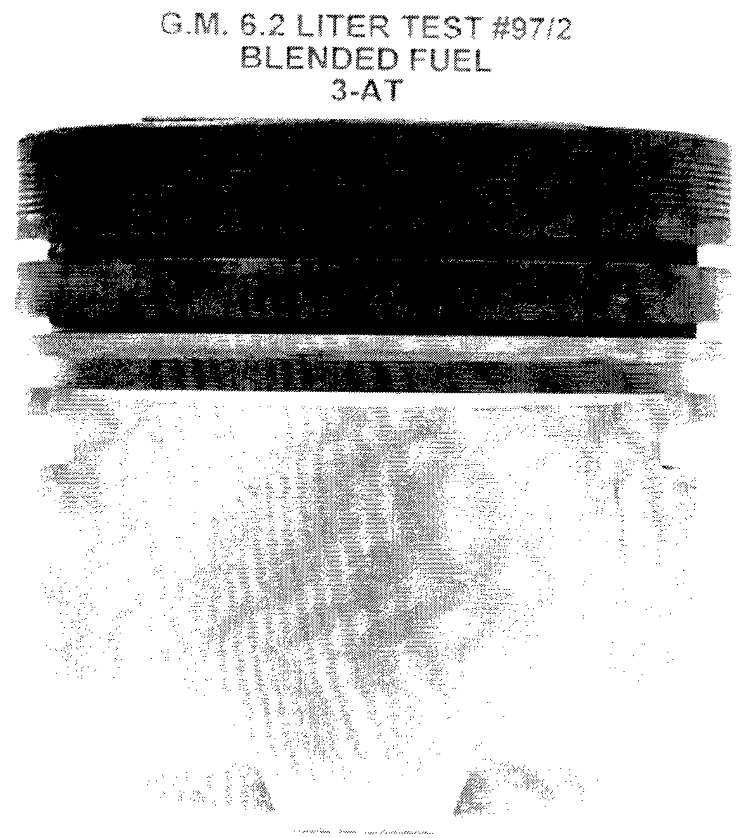


Figure B-23. G.M. 6.2 Liter Test 97-2, Blended Fuel, Piston 3-AT

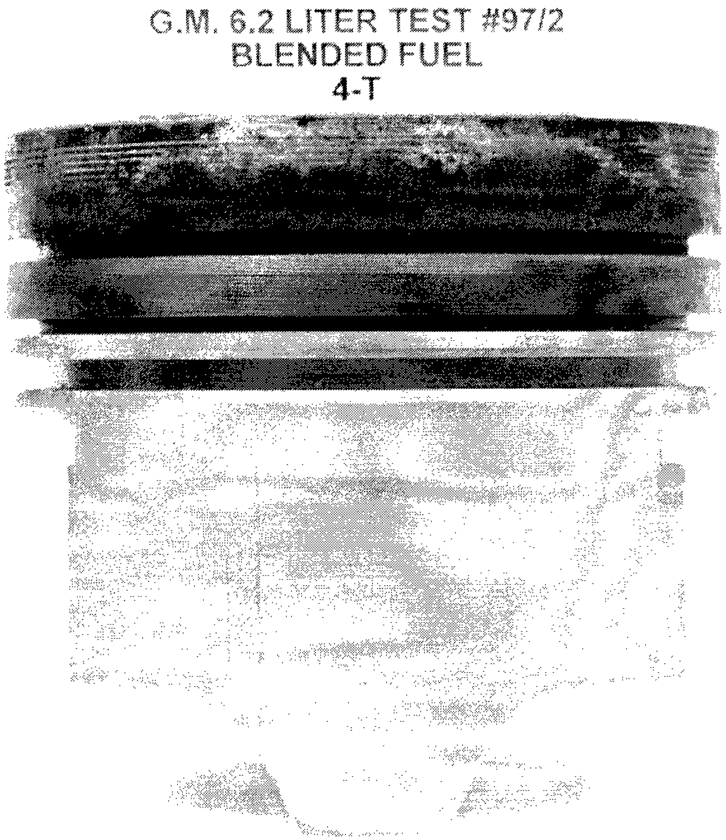


Figure B-24. G.M. 6.2 Liter Test 97-2, Blended Fuel, Piston 4-T

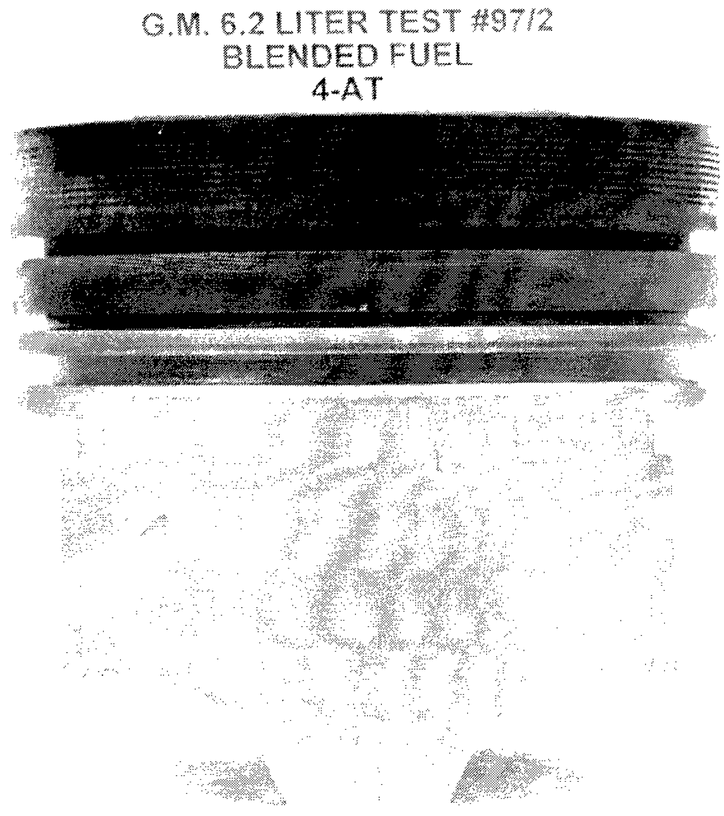


Figure B-25. G.M. 6.2 Liter Test 97-2, Blended Fuel, Piston 4-AT

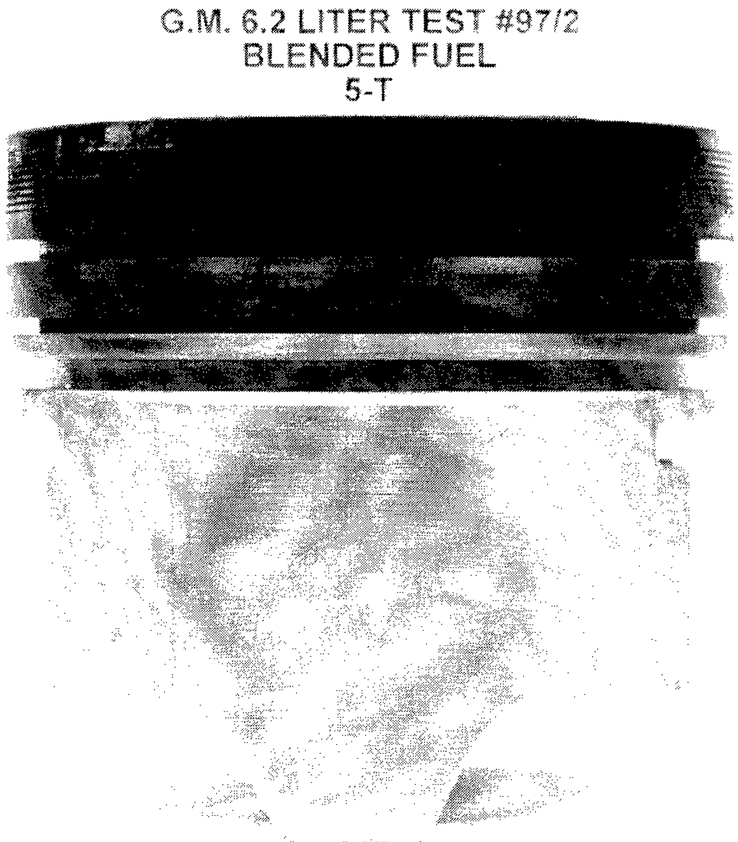


Figure B-26. G.M. 6.2 Liter Test 97-2, Blended Fuel, Piston 5-T

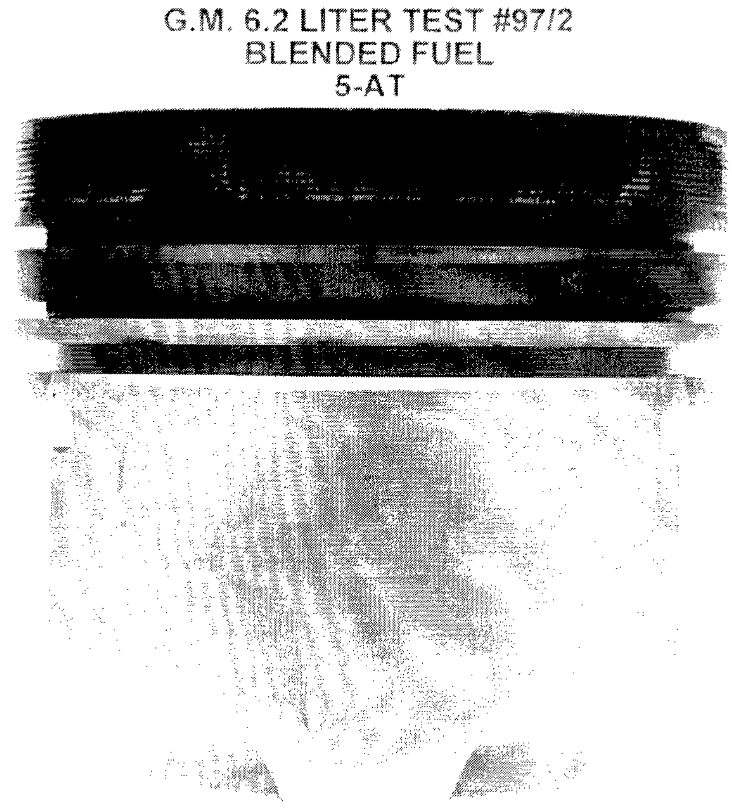


Figure B-27. G.M. 6.2 Liter Test 97-2, Blended Fuel, Piston 5-AT

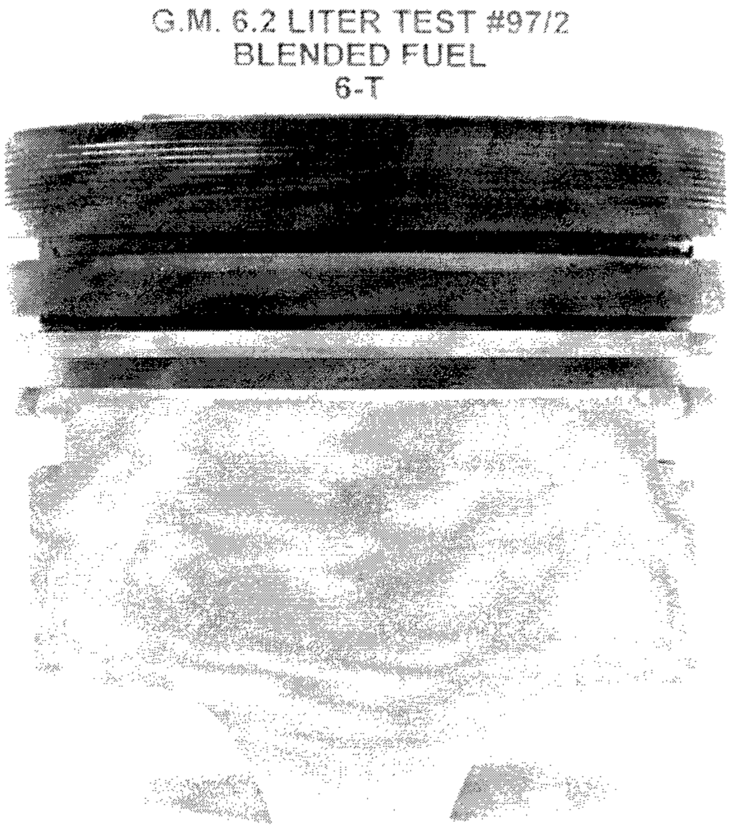


Figure B-28. G.M. 6.2 Liter Test 97-2, Blended Fuel, Piston 6-T

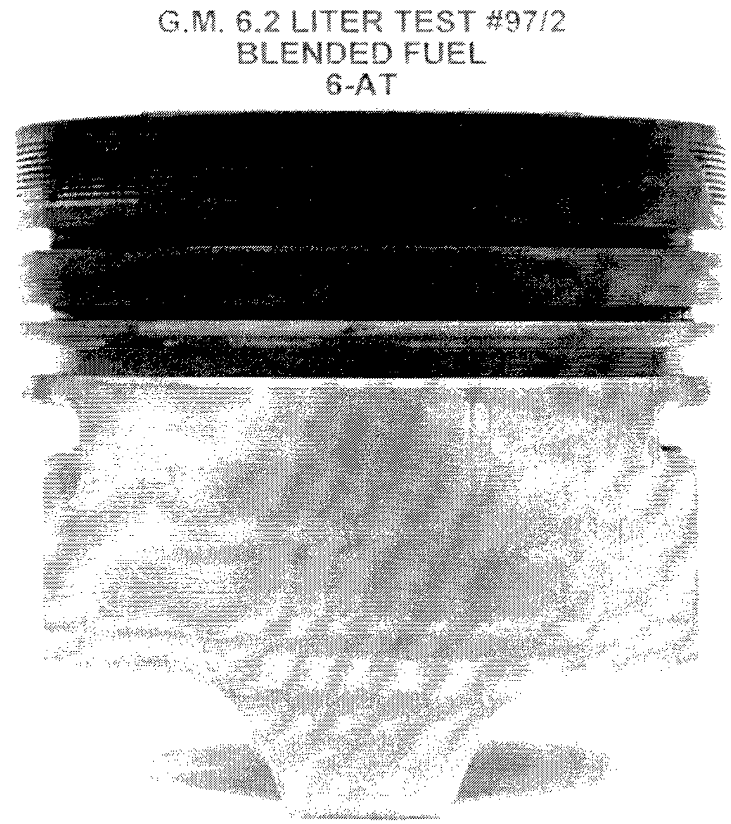


Figure B-29. G.M. 6.2 Liter Test 97-2, Blended Fuel, Piston 6-AT

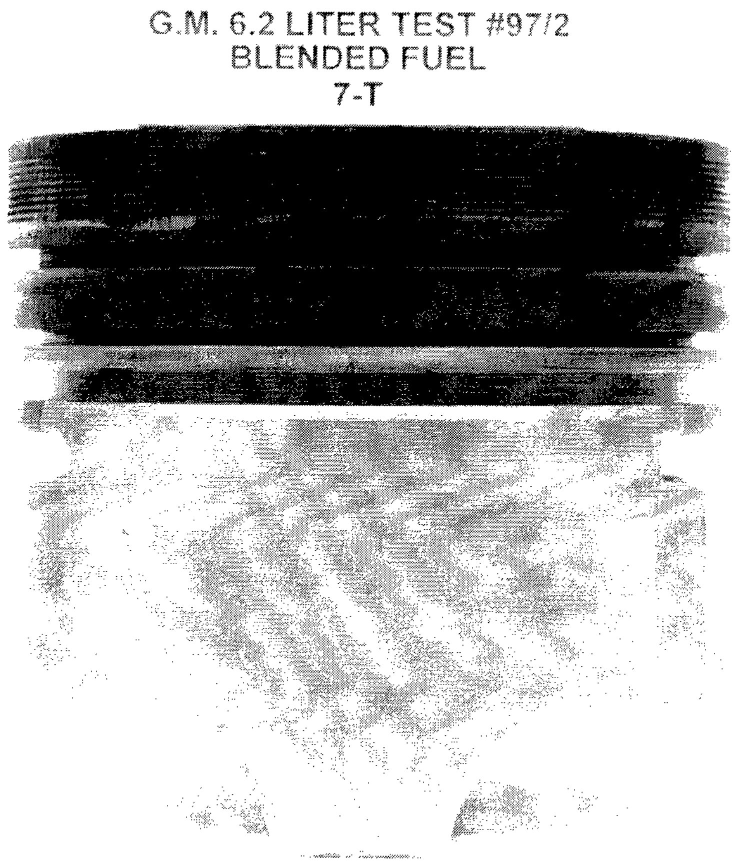


Figure B-30. G.M. 6.2 Liter Test 97-2, Blended Fuel, Piston 7-T

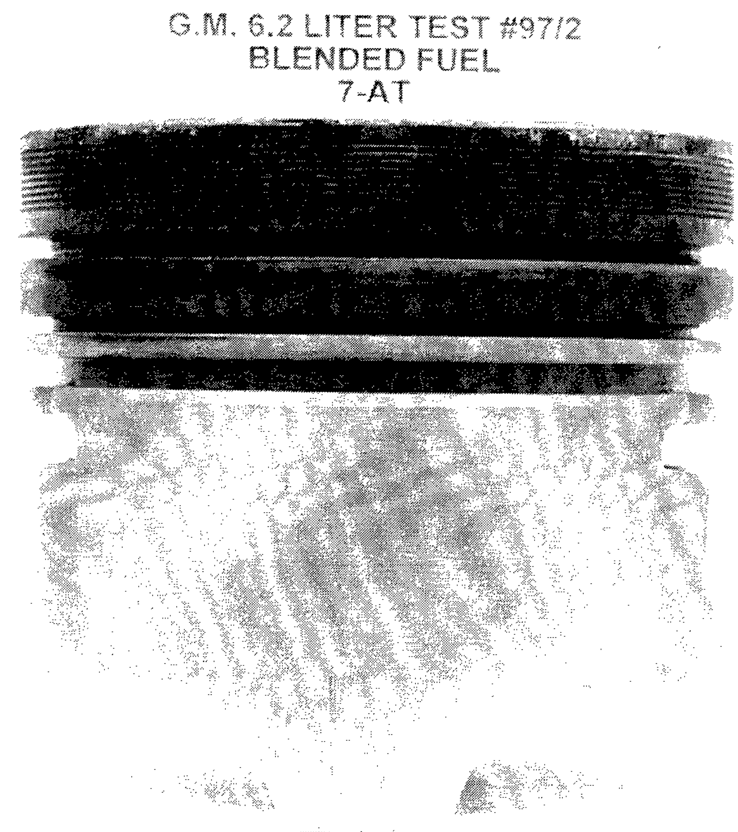


Figure B-31. G.M. 6.2 Liter Test 97-2, Blended Fuel, Piston 7-AT

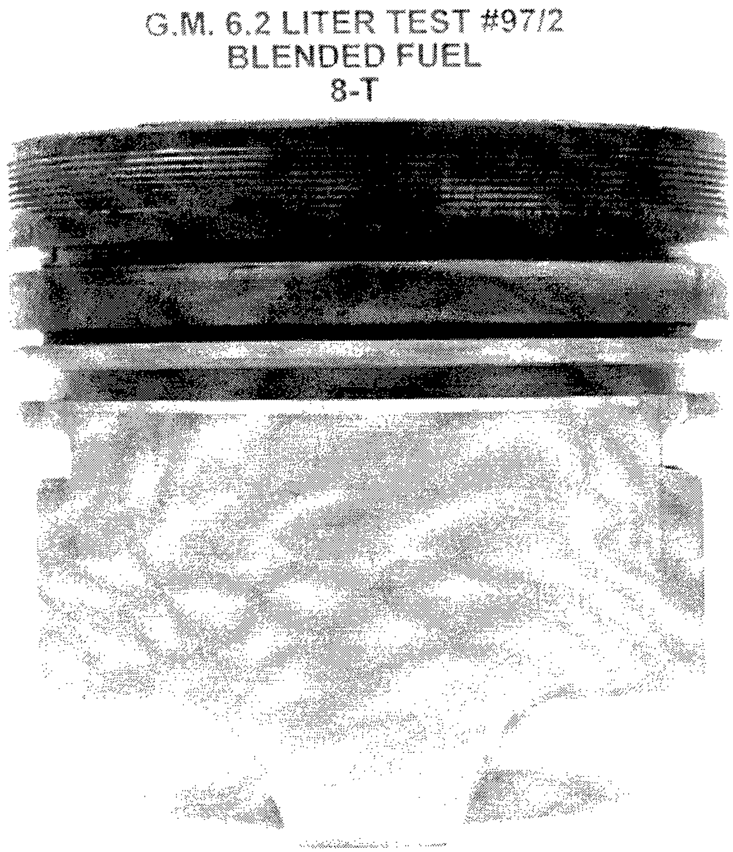


Figure B-32. G.M. 6.2 Liter Test 97-2, Blended Fuel, Piston 8-T

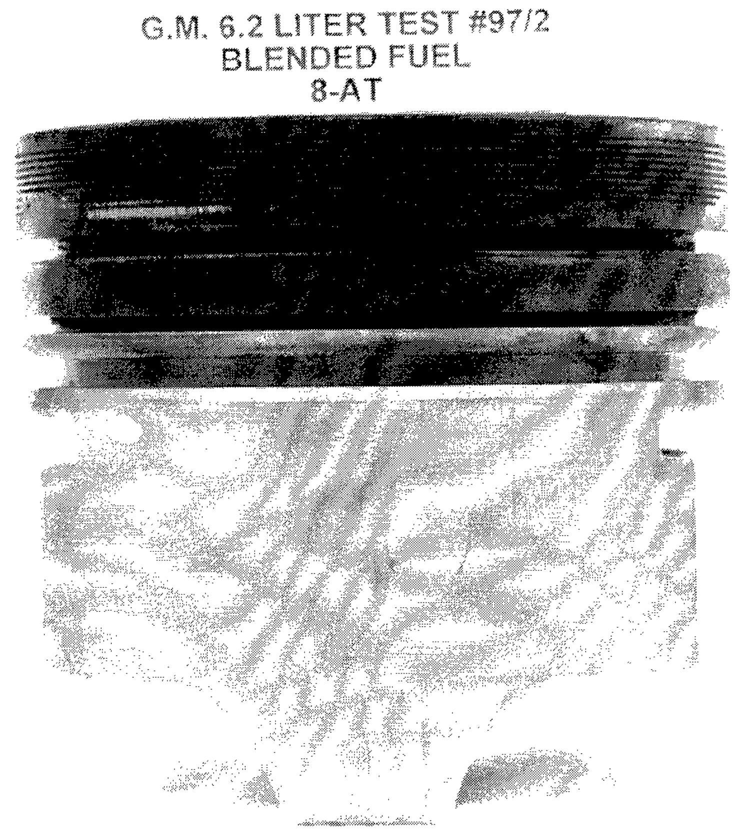


Figure B-33. G.M. 6.2 Liter Test 97-2, Blended Fuel, Piston 8-AT

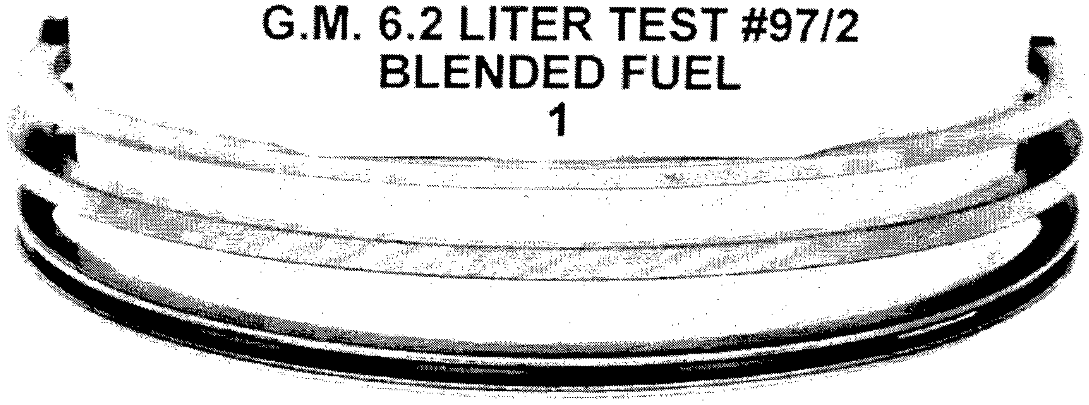


Figure B-34. G.M. 6.2 Liter Test 97-2, Blended Fuel, Cylinder 1 Rings

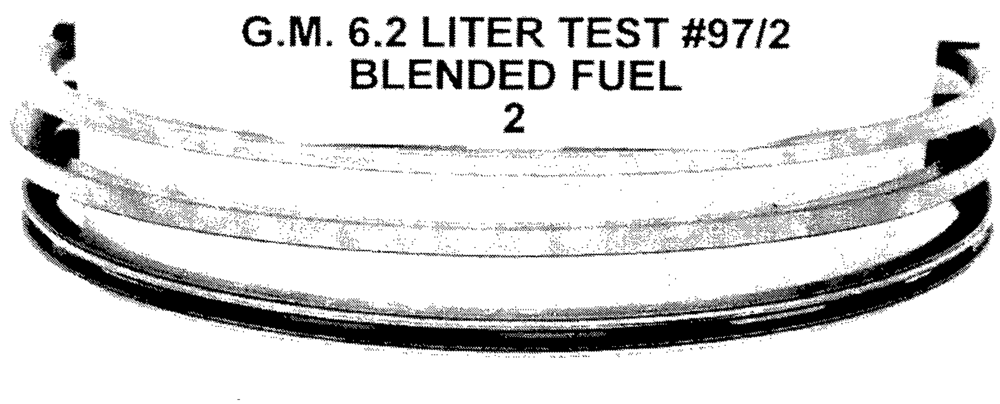


Figure B-35. G.M. 6.2 Liter Test 97-2, Blended Fuel, Cylinder 2 Rings

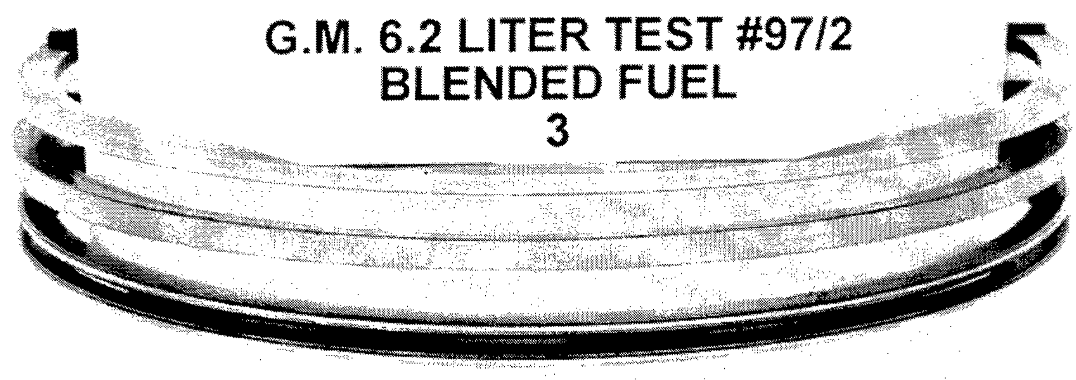


Figure B-36. G.M. 6.2 Liter Test 97-2, Blended Fuel, Cylinder 3 Rings

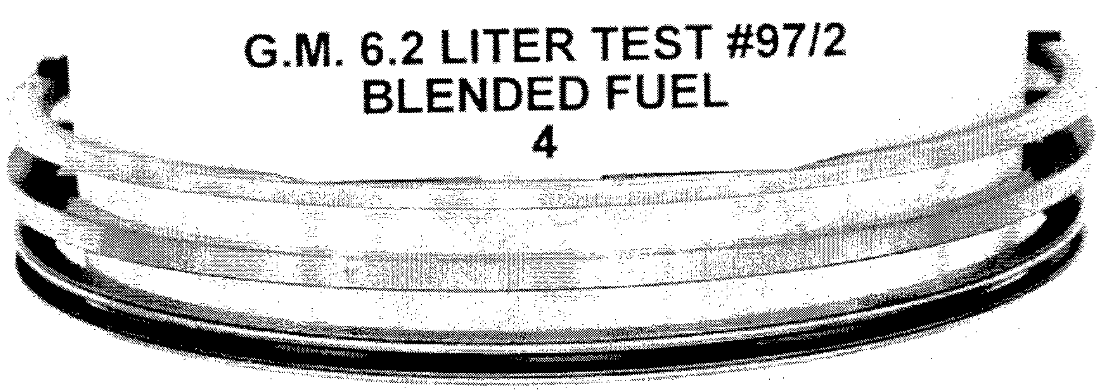


Figure B-37. G.M. 6.2 Liter Test 97-2, Blended Fuel, Cylinder 4 Rings

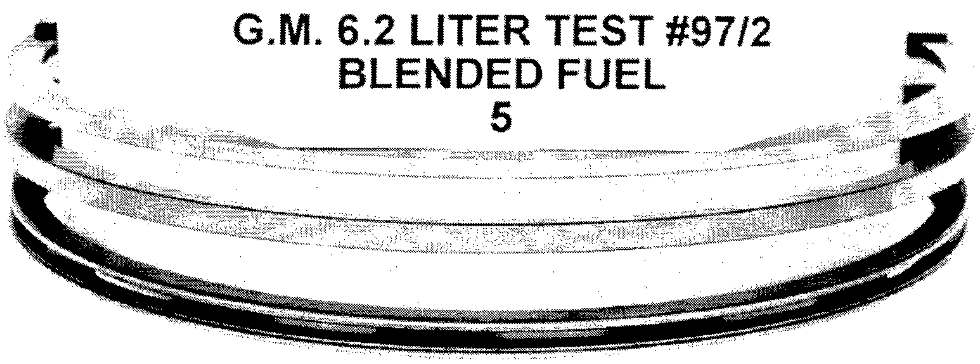


Figure B-38. G.M. 6.2 Liter Test 97-2, Blended Fuel, Cylinder 5 Rings

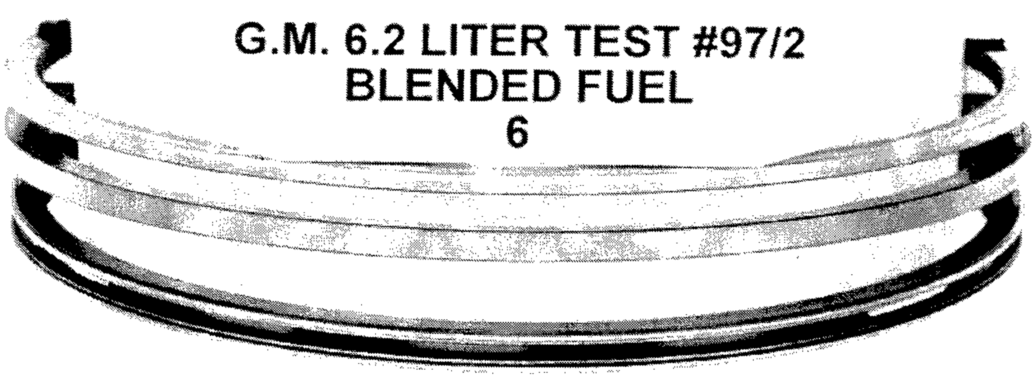


Figure B-39. G.M. 6.2 Liter Test 97-2, Blended Fuel, Cylinder 6 Rings

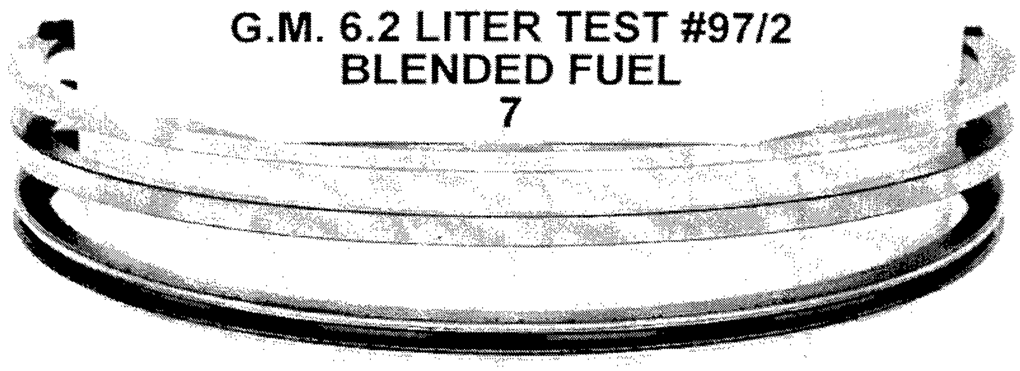


Figure B-40. G.M. 6.2 Liter Test 97-2, Blended Fuel, Cylinder 7 Rings

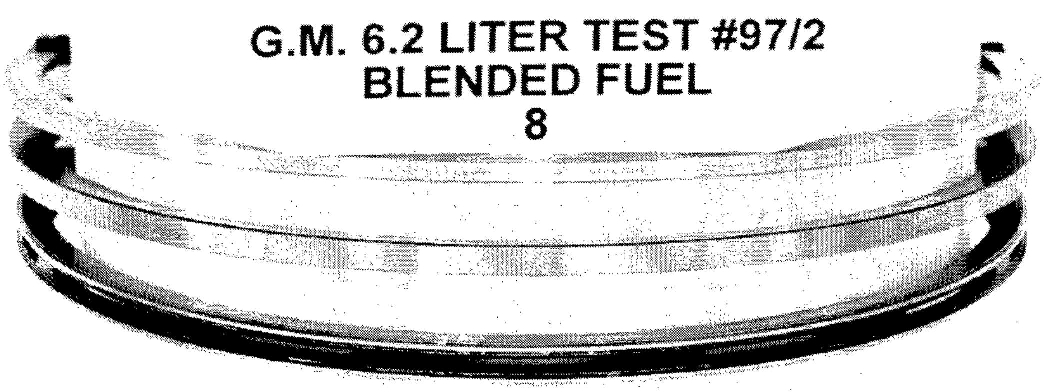


Figure B-41. G.M. 6.2 Liter Test 97-2, Blended Fuel, Cylinder 8 Rings

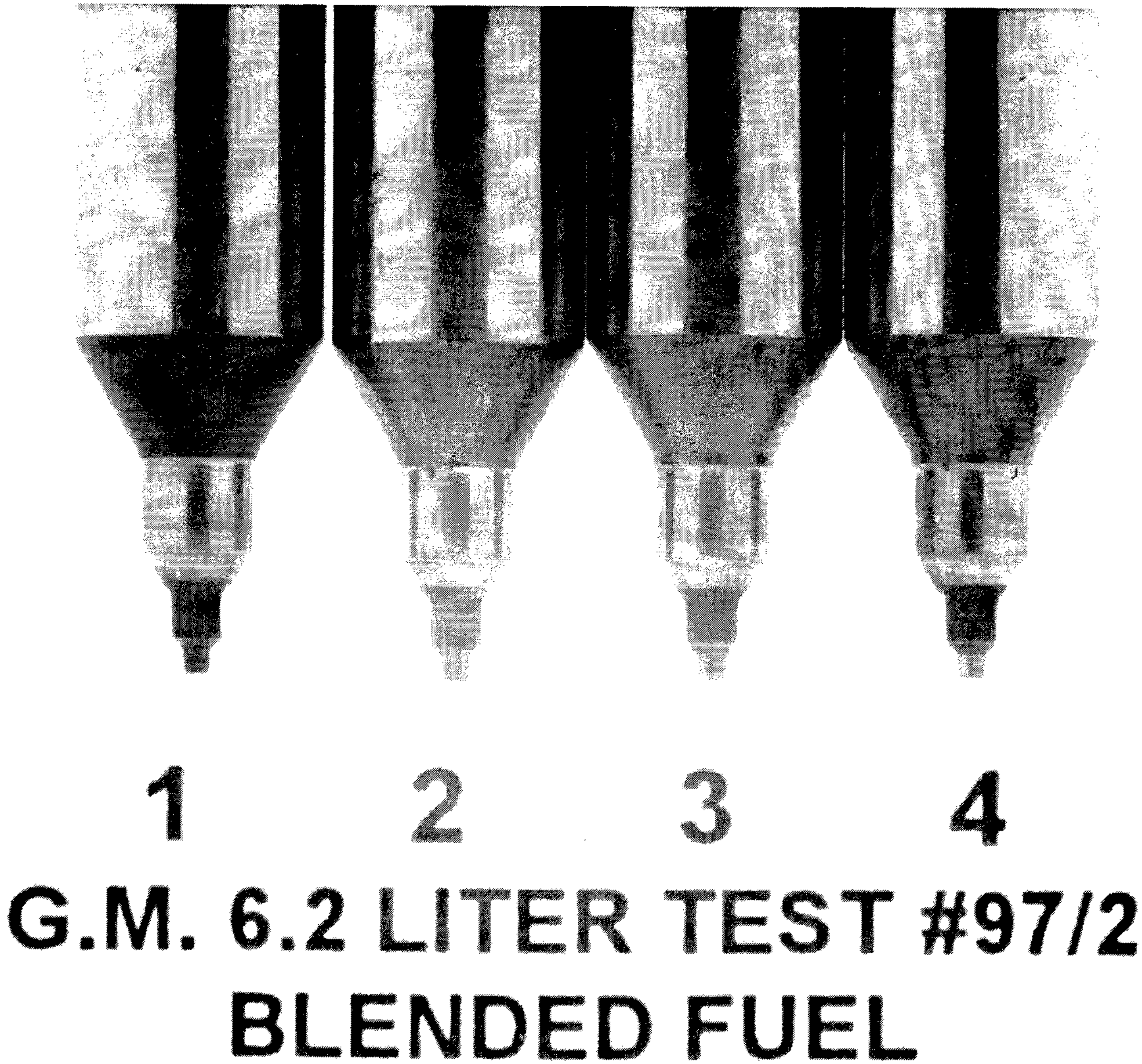


Figure B-42. G.M. 6.2 Liter Test 97-2, Blended Fuel, Injectors 1, 2, 3, and 4

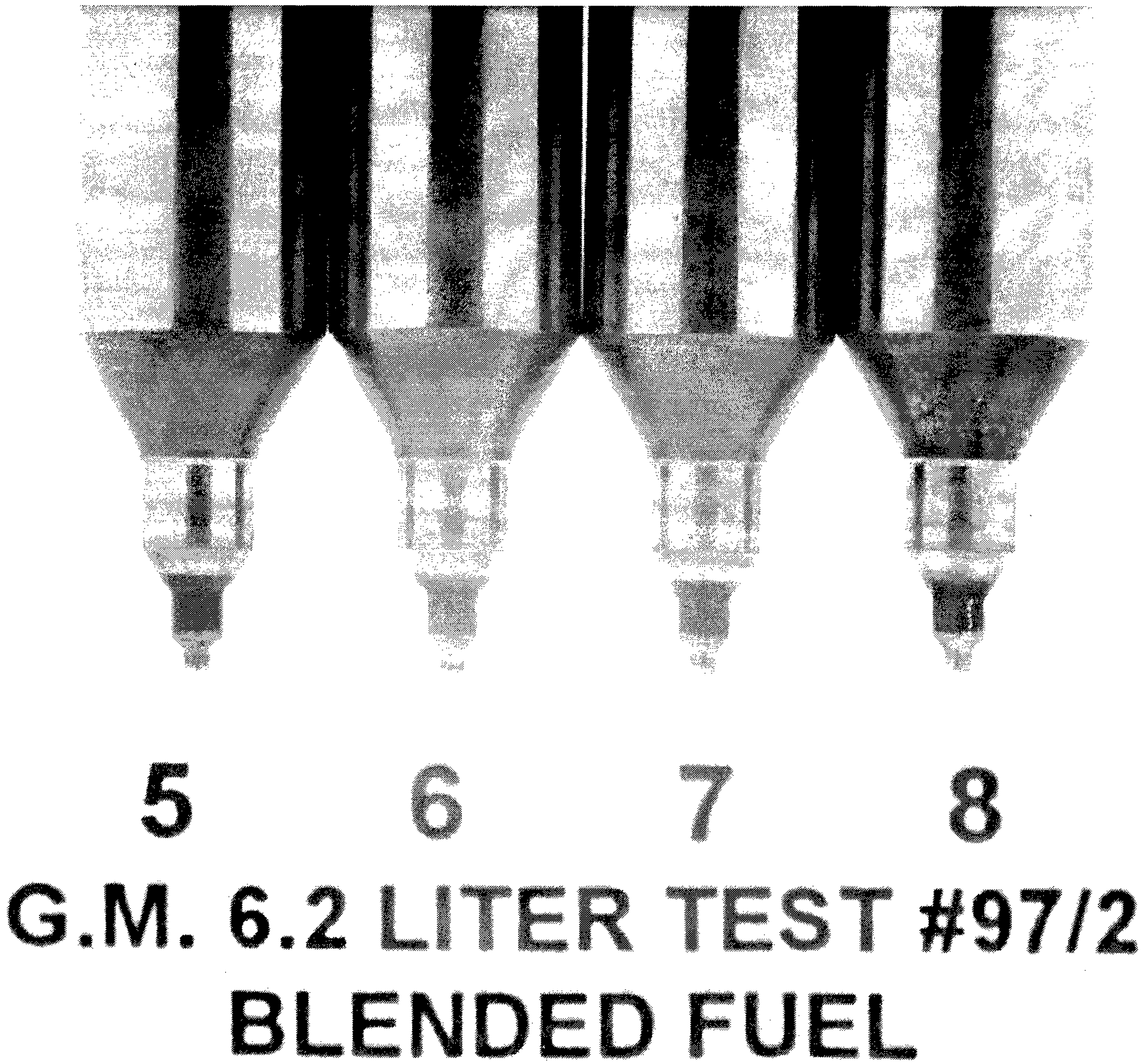


Figure B-43. G.M. 6.2 Liter Test 97-2, Blended Fuel, Injectors 5, 6, 7, and 8

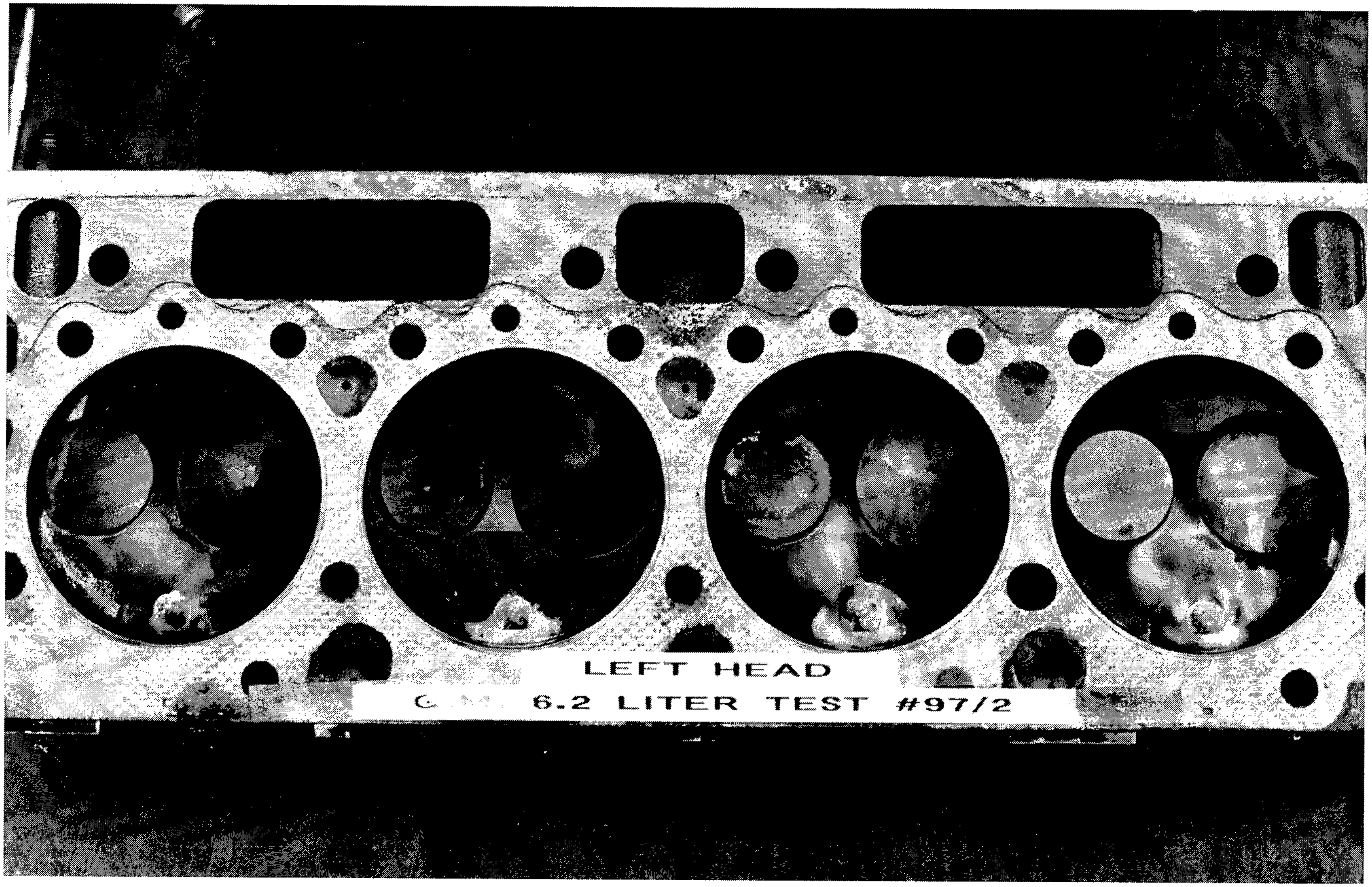


Figure B-44. G.M. 6.2 Liter Test 97-2, Blended Fuel, Left Head

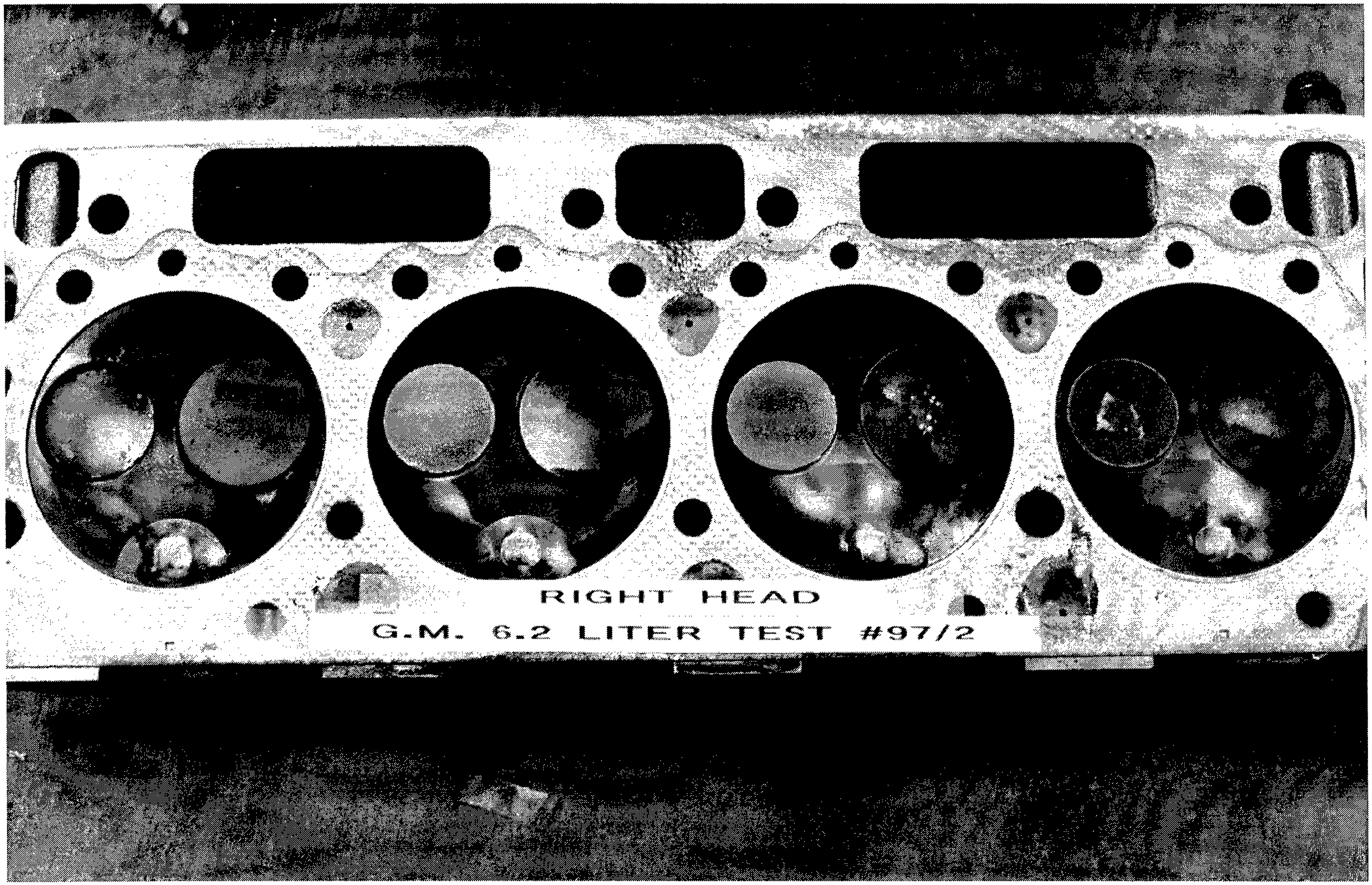


Figure B-45. G.M. 6.2 Liter Test 97-2, Blended Fuel, Right Head

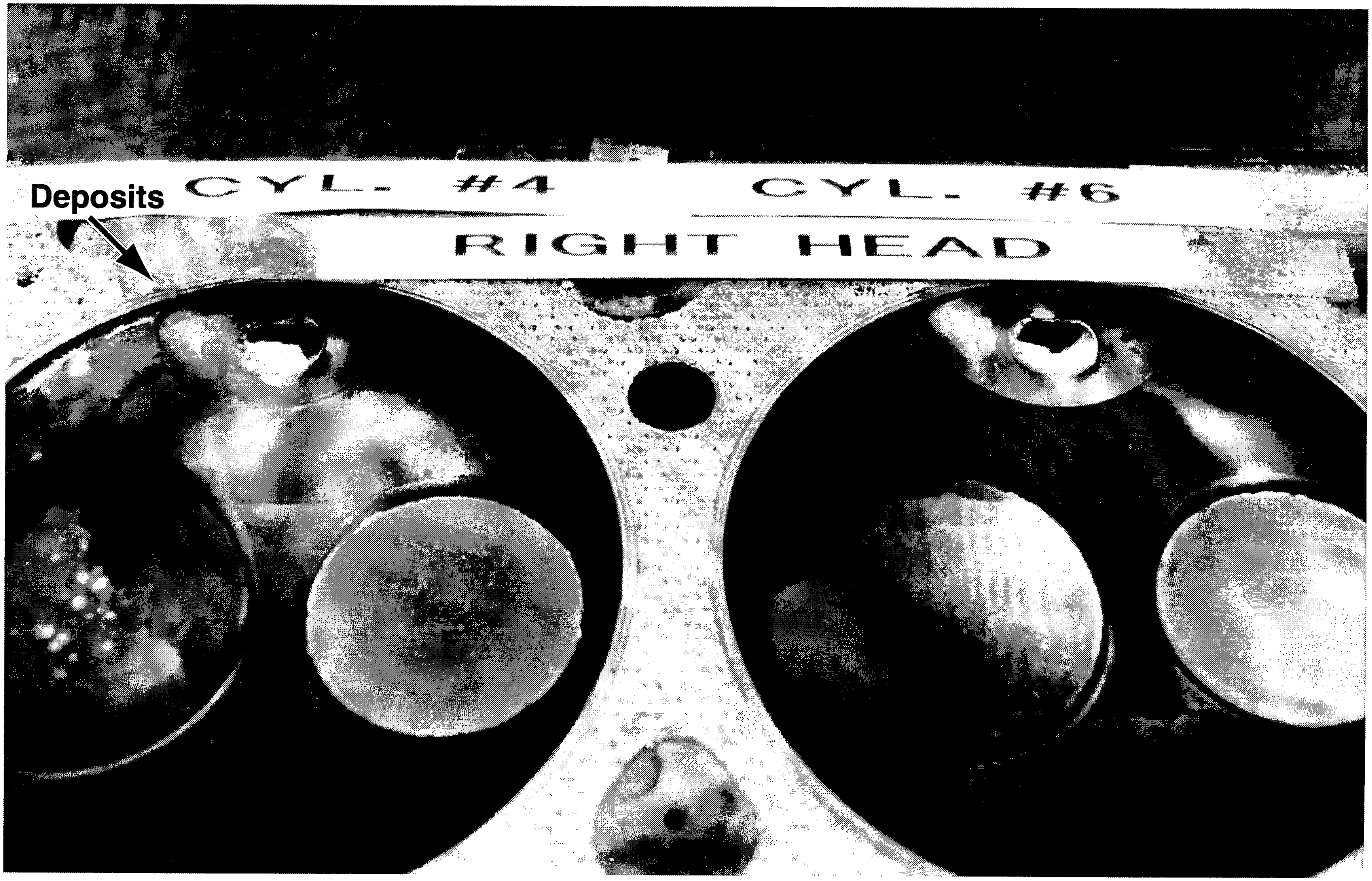


Figure B-46. G.M. 6.2 Liter Test 97-2, Blended Fuel, Right Head, Cylinders 4 and 6

Figure B-47. G.M. 6.2 Liter Test 97-2, Blended Fuel, Left Bank, Cylinder 5

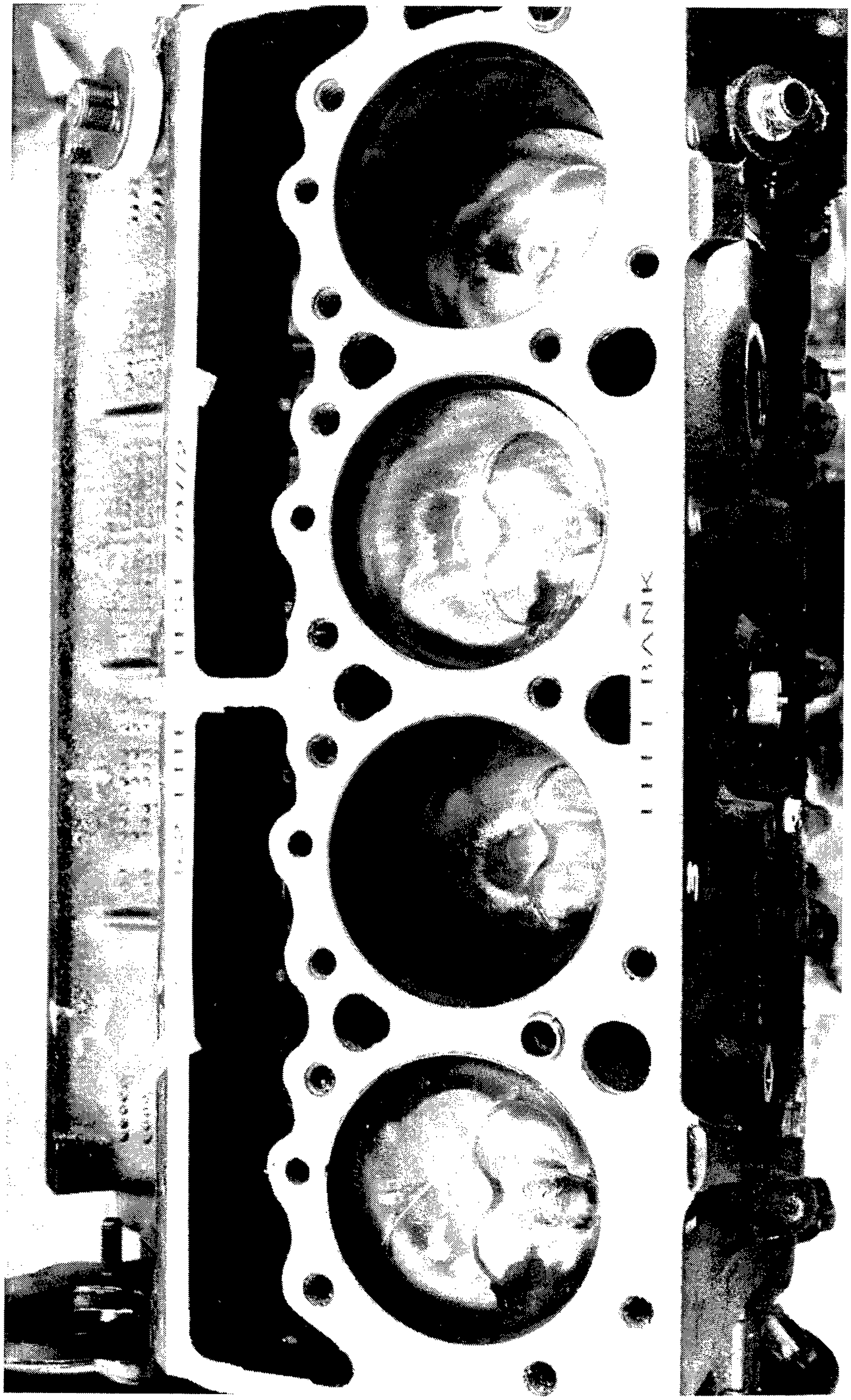


Figure B-48. <u>G.M. 6.2 Liter Test 97-2, Blended Fuel, Left Bank</u>

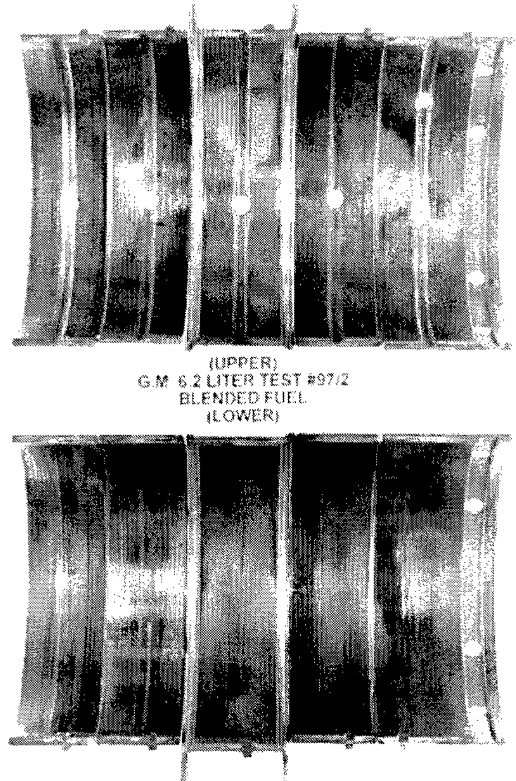


Figure B-49. <u>**G.M. 6.2 Liter Test 97-2, Blended Fuel, BeaCylinders (Upper and Lower)**</u>

APPENDIX C
6V53T Neat JP-8 Fuel Evaluation –Test 39

Baseline, 6V-53T Engine

Test Lubricant: REO-203 (AL-12634-L)
Test Fuel: JP-8 (AL-12780-F)
Test No.: Test 39
Date: March 1984

Conducted For

U.S. Army Tank-Automotive Research, Development and Engineering Center
Logistics Equipment Directorate
Fort Belvoir, Virginia 22060-5606

By

TARDEC Fuels and Lubricants Research Facility (SwRI)
Southwest Research Institute
P.O. Drawer 28510
San Antonio, Texas 78228-0510

6V-53T
TEST 39
ENGINE REBUILD MEASUREMENTS*
MODEL NUMBER: 5063-5395
SERIAL NUMBER: 6D-157211

	Minimum	Maximum	Average	Specified Limits
Cylinder Block Bore				
Inside Diameter (Bottom)	4.3567	4.3578	4.357	4.3565 - 4.3575
Out of Round	0.0001	0.0008	0.0005	0.0015 Max
Taper	0.0000	0.0004	0.0001	0.0015 Max
Cylinder Liners (Installed)				
Inside Diameter	3.8754	3.8766	3.876	3.8752 - 3.8767
Out of Round	0.0000	0.0007	0.0003	0.0015 Max
Taper	0.0000	0.0006	0.0033	0.0015 Max
Piston Diameter (at skirt)	3.8677	3.8686	3.8681	3.8669 - 3.8691
Piston Skirt to Cylinder Liner Clearance	0.007	0.0086	0.0082	0.0061 - 0.0098
Compression Rings				
Gap (No. 1, Fire Ring)	0.031	0.035	0.034	0.020 - 0.046
Gap (Nos. 2,3,4)	0.025	0.033	0.029	0.020 - 0.036
Ring-to-Groove Clearance				
Top (No. 1, Fire Ring)	0.003	0.004	0.004	0.003 - 0.006
No. 2, Compression Ring	0.008	0.008	0.008	0.007 - 0.010
No. 3 and 4, Compression Rings	0.005	0.006	0.006	0.005 - 0.008
Oil Control Rings, Nos. 5, 6, 7				
Gap	0.013	0.016	0.014	0.010 - 0.025
Ring-to-Groove Clearance	0.002	0.004	0.003	0.0015 - 0.0055
Piston Pin				
Pin-to-Piston Bushing Clearance	0.0028	0.003	0.0029	0.0025 - 0.0034
Pin-to-Connecting Rod Bushing Clearance	0.0013	0.0017	0.0014	0.0010 - 0.0019
Connecting Rod Bearing--to Journal Clearance	0.0021	0.0032	0.0026	0.0011 - 0.0041
Main Bearing-to-Journal Clearance	0.0041	0.0044	0.0042	0.0010 - 0.0040
Camshaft Bearing-to-Journal Clearance	0.005	0.0056	0.0053	0.0045 - 0.0060

* Measurements are in inches.

6V-53T
Test 39

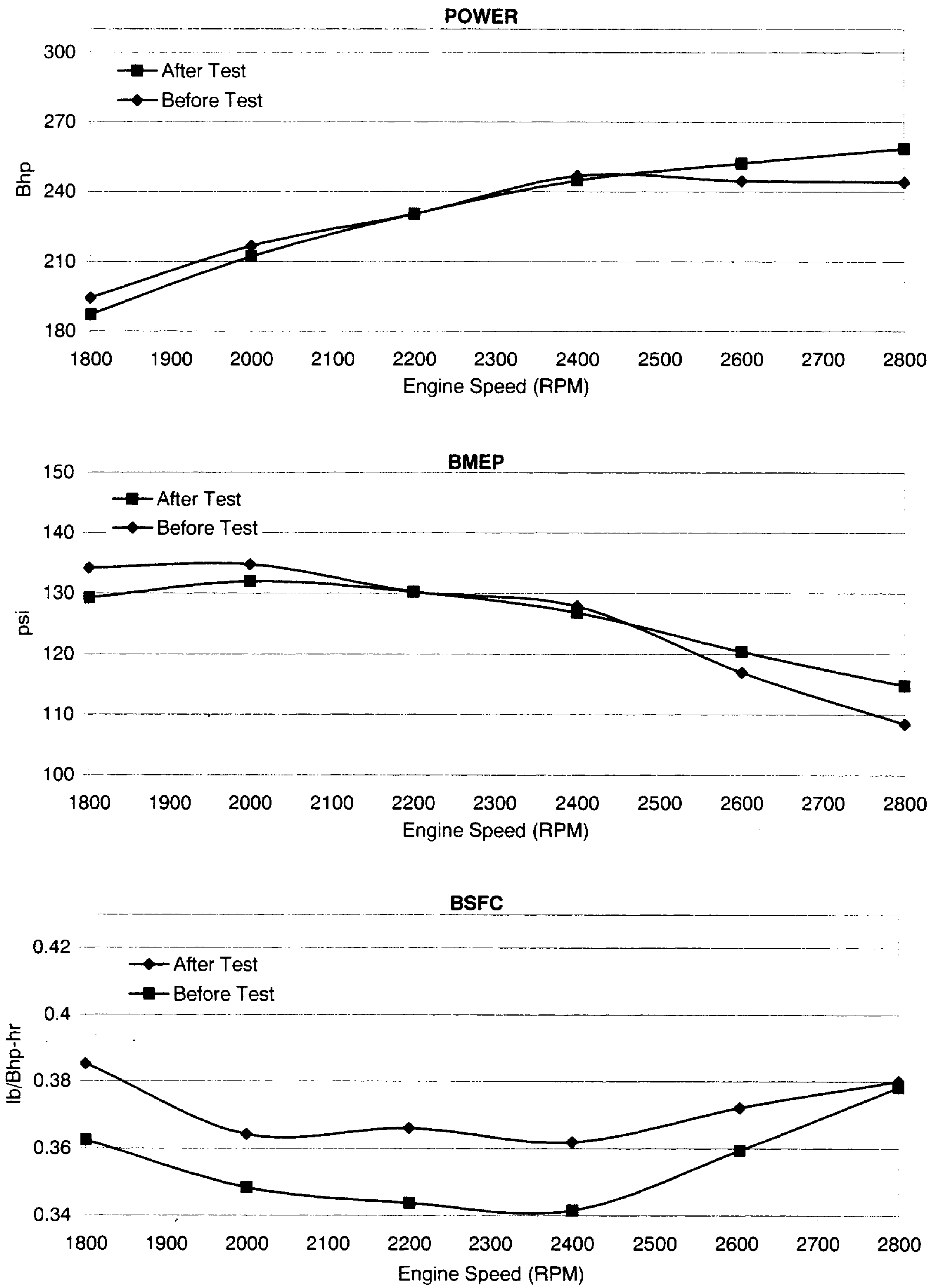


Figure C-1. Full Load Performance

6V-53T
Test 39
Operating Conditions Summary
Model Number: 5063-5395
Serial Number: 6D-157211

	Maximum Power Mode (2800 RPM)		Maximum Torque Mode (2200 mode)	
	Mean	Standard Deviation	Mean	Standard Deviation
Engine Speed, rpm	2800	5.38	2200	3.56
Torque, ft-lb	481	4.50	559	5.92
Fuel Consumption, lb/hr	97.7	0.65	83.9	0.415
Observed Power, Bhp	256	2.34	234	2.40
BSFC, lb/Bhp-hr	0.381	0.003	0.359	0.004
Temperatures, °F				
Exhaust before Turbo	901	28.4	900	25.7
Exhaust after Turbo	747	18.4	793	23.8
Water Jacket Inlet	159	1.45	159	1.49
Water Jacket Outlet	170	1.62	170	1.56
Oil Sump	234	2.87	226	2.67
Fuel at Filter	97	9.23	93	2.25
Inlet Air	92	3.21	93	4.29
Airbox	263	2.76	221	2.59
Pressures				
Exhaust before Turbo, psi	9.32	0.318	5.35	0.176
Exhaust after Turbo, in. Hg	2.09	0.093	1.15	0.07
Compressor Discharge, psi	9.76	0.435	6.73	0.873
Blower Discharge, psi	16.4	0.515	9.05	0.367
Oil Gallery, psi	57.1	0.636	52.6	0.724
Intake Vacuum, in. H_2O	3.9	0.09	2.3	0.06
Ambient Conditions				
Dry Bulb Temperature, °F	56.5	8.92	54.8	8.44
Wet Bulb Temp., °F	46.7	7.41	47.1	8.33
Barometric Pressure, in. Hg	29.2	0.17		

6V-53T
Test 39
FUEL ANALYSIS
Fuel: AL-12780-F

Property		ASTM Method	Value
Density, kg/L		D 1298	0.7793
API Gravity		D 1298	50
Distillation, °F	IBP	D 86	308
	10%	D 86	321
	20%	D 86	322
	30%	D 86	324
	40%	D 86	326
	50%	D 86	328
	60%	D 86	330
	70%	D 86	332
	80%	D 86	336
	90%	D 86	341
	End Point	D 86	394
	Residue, vol%	D 86	0.3
Distillation, °C	IBP	D2887	140.1
	10%	D2887	153.1
	20%	D2887	160.2
	30%	D2887	165.9
	40%	D2887	170.1
	50%	D2887	173
	60%	D2887	176.7
	70%	D2887	179
	80%	D2887	181.3
	90%	D2887	186
	End Point	D2887	215.2
Flash Point, °F		D 56	103
Freeze Point, °C		D 2386	-59
Cetane Number		D 613	40.3
Kinematic Viscosity at 40°C, cSt		D 445	0.89
Cu Corrosion, at 100°C		D 130	1A
Total Acid Number		D 3242	0
Saturates, vol%		D 1319	80.7
Olefins, vol%		D 1319	1.4
Aromatics, vol%		D 1319	17.9
Sulfur, wt%		D 2622	<0.01
Mercaptan Sulfur, wt%		D 3227	<0.001
Saybolt Color		D 156	+26
Net Heat of Combustion, Btu/lb		D 1405	18548
Carbon, wt%		D 3178	85.49+-0.02
Hydrogen, wt%		D 3178	14.01+-0.01
Particulate Contamination, mg/L		D 2276	0.8
Existent Gum, mg/100 mL		D 381	0.4
Water Reaction		D 1094	1B
Water Separation Index, Modified		D 2550	76
Water Separation Characteristics, by Microseparator		D 3948	88
Fuel System Icing Inhibitor, %		Fed. Std. 791	0.1
Electrical Conductivity, pS/m		D 3114	17

6V-53T
Test 39
LUBRICANT ANALYSIS
Lubricant: AL-12634-L

	ASTM Test Method	Test Time, Hours												
		0	20	40	60	80	100	120	140	160	180	200	220	240
Kinematic Viscosity at 40°C (104°F) cSt	D 445	102.90	--	--	88.70	--	--	92.44	--	--	91.05	--	--	93.67
Kinematic Viscosity at 100°C (212°F) cSt	D 445	11.66	10.48	10.72	10.89	10.99	11.05	11.13	10.88	10.91	11.01	11.01	11.17	11.22
Total Acid Number mg KOH/g	D 664	2.71	--	--	2.95	--	--	3.27	--	--	2.97	--	--	3.26
Total Base Number mg KOH/g	D 4739	5.32	--	--	3.91	--	--	3.73	--	--	4.22	--	--	3.14
Pentane B Insolubles wt%	D 893	0.02	--	--	0.14	--	--	0.23	--	--	0.14	--	--	0.20
Toluene B Insolubles wt%	D 893	0.01	--	--	0.12	--	--	0.18	--	--	0.12	--	--	0.17
Flash Point, °C	D 92	238.00	--	--	--	--	--	227.00	--	--	--	--	--	224.00

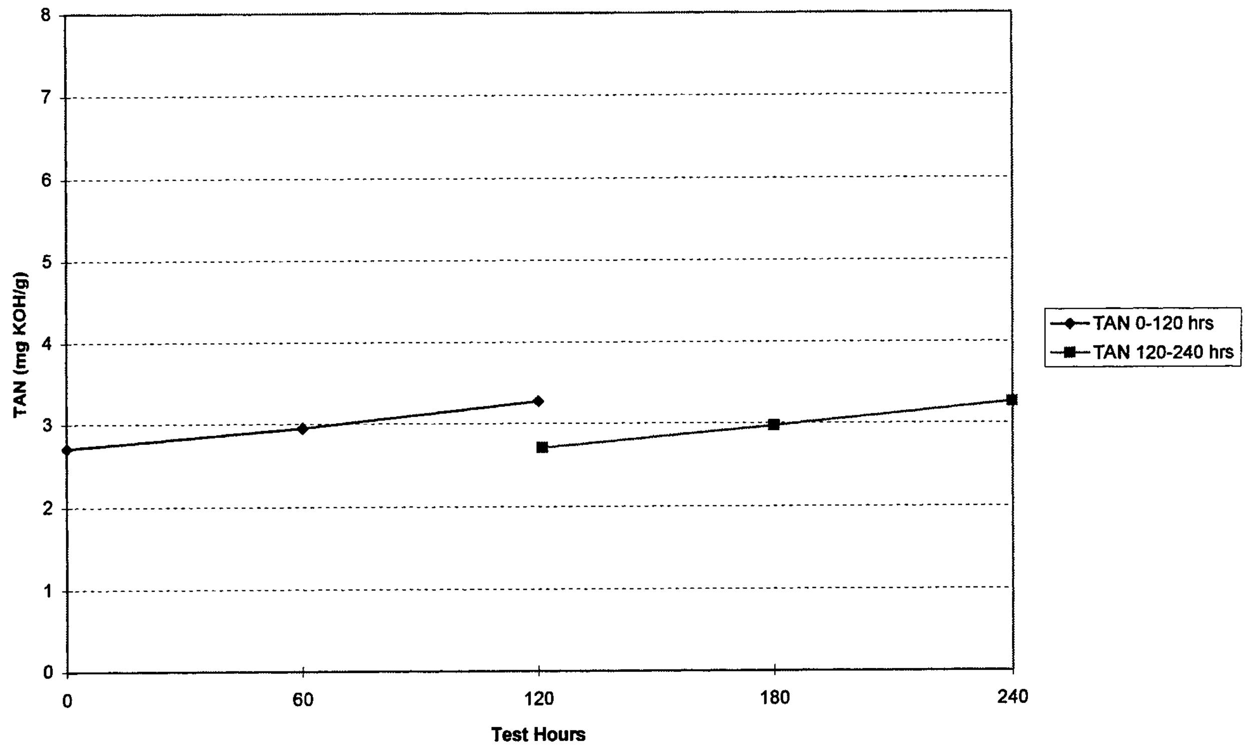


Figure C-2. Total Acid Number

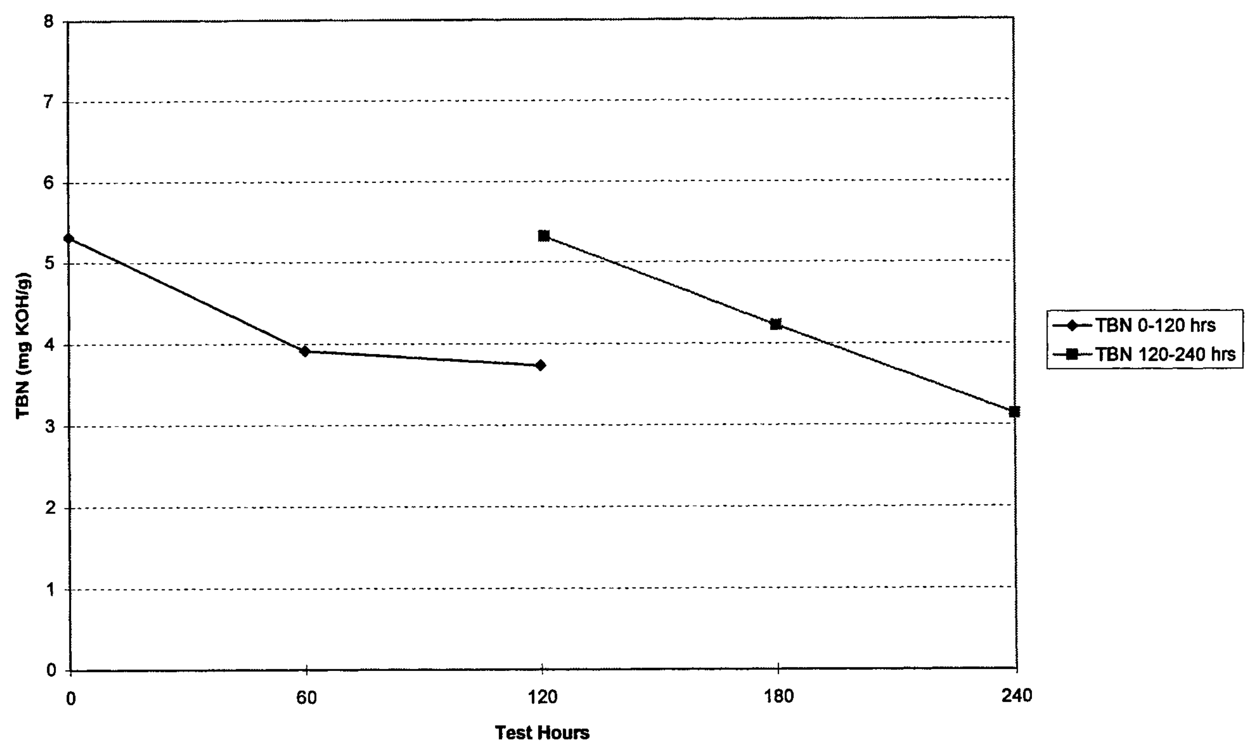


Figure C-3. Total Base Number

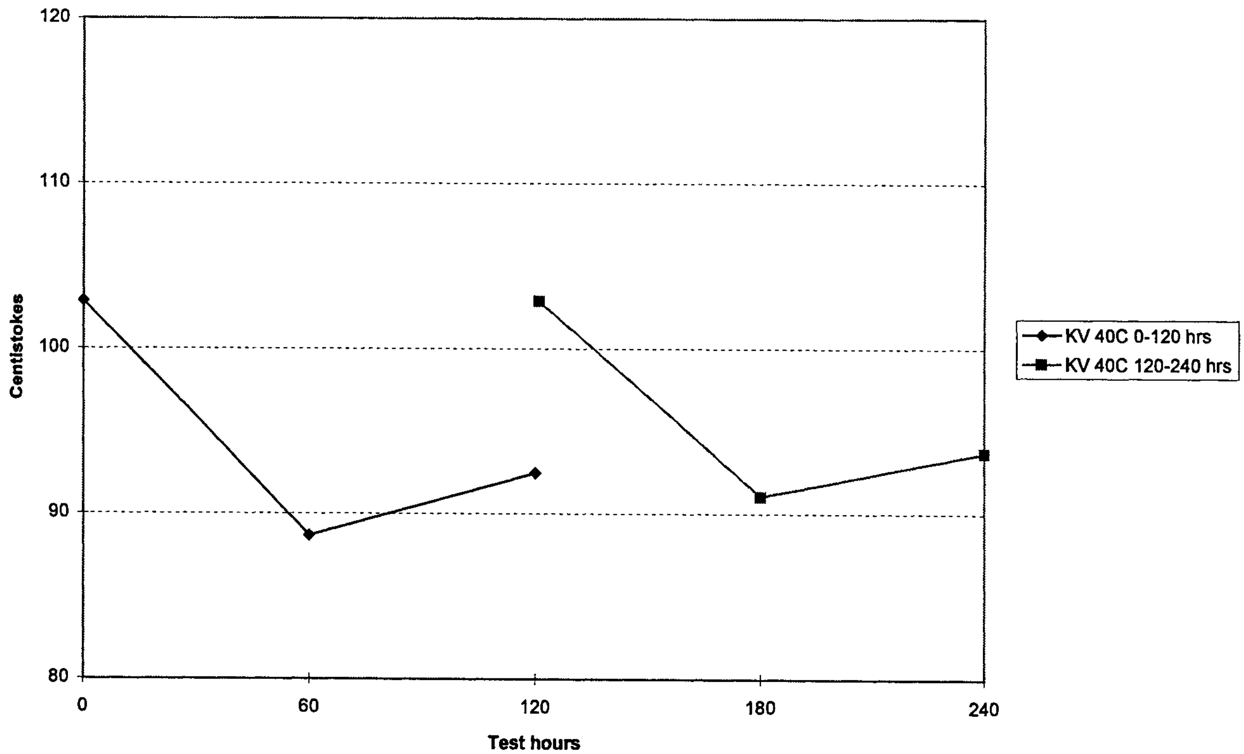


Figure C-4. **Kinematic Viscosity at 40°C**

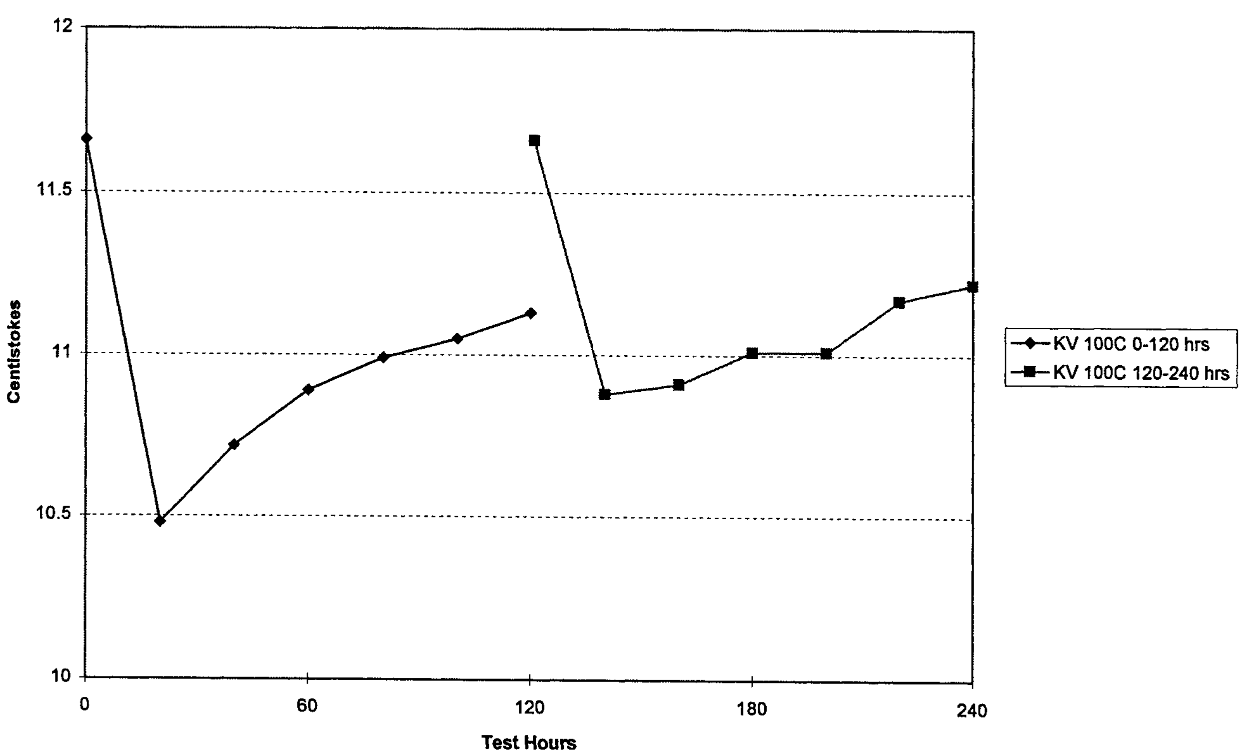


Figure C-5. **Kinematic Viscosity at 100°C**

6V-53T
Test 39
TOTAL CONSUMPTION AND WEAR METALS BY XRF
Lubricant: AL-12634-L

Test Time, Hours	Oil Consumed, lb	Cumulative Oil Consumption	Wear Metals, ppm Fe	Cu	Pb
0	0.00	0.00	59	11	<60
20	6.44	6.44	83	<10	<60
40	8.59	15.03	97	<10	<60
60	8.29	23.32	83	<10	<60
80	10.12	33.44	103	<10	<60
100	8.62	42.06	134	<10	<60
120	6.85	48.91	119	<10	<60
140	7.10	56.01	45	<10	<60
160	9.39	65.40	51	<10	<60
180	9.80	75.20	49	<10	<60
200	9.94	85.14	52	<10	<60
220	9.70	94.84	46	<10	<60
240	6.86	101.70	49	<10	<60

Total oil consumed: 101.7 lb
Average oil consumption rate: 0.42 lb/hr

NOTE: Oil was changed at 120 hours.

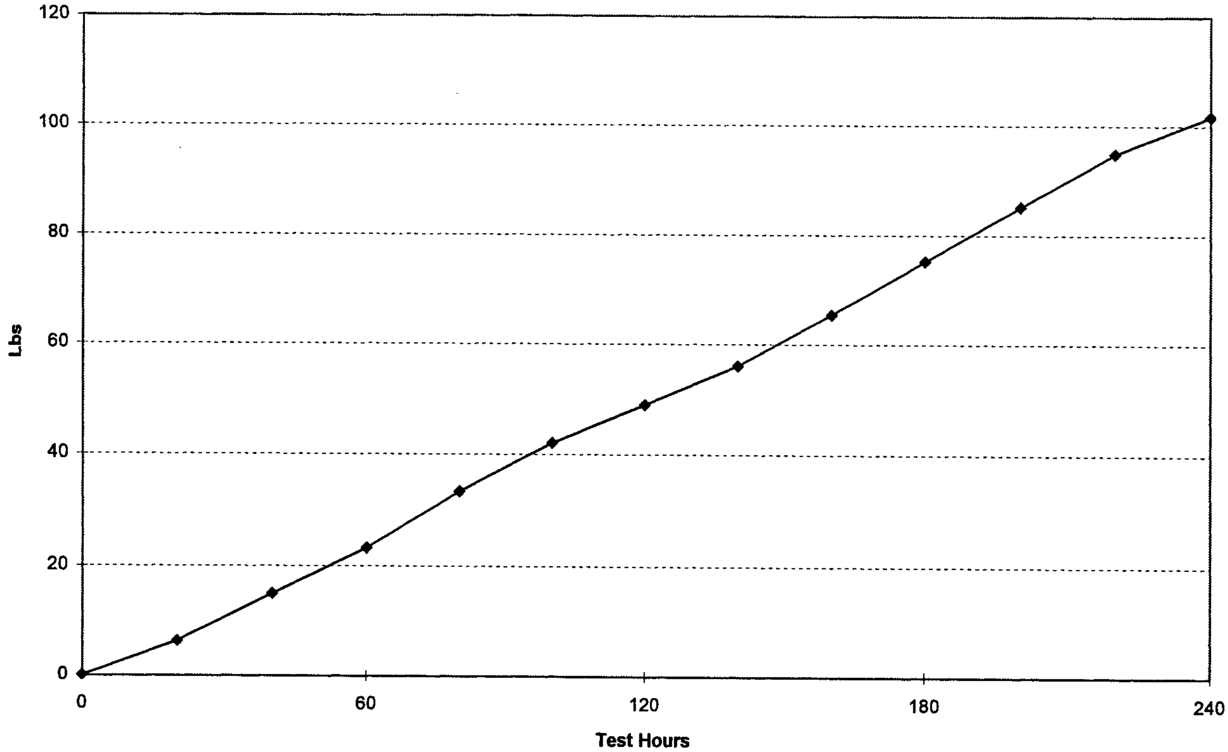


Figure C-6. Cumulative Oil Consumption

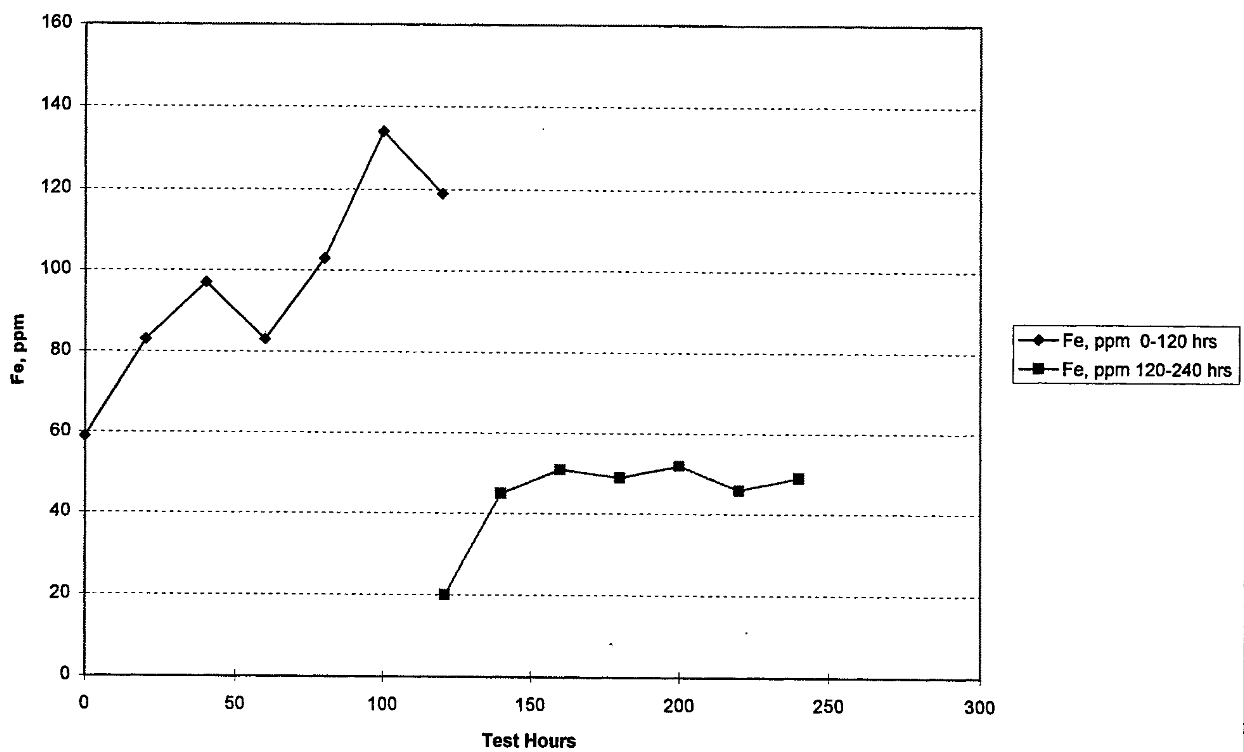


Figure C-7. Used Oil Iron Content

6V-53T
Test 39
WEAR MEASUREMENTS*
Lubricant: AL-12634-7

Cylinder Liner Bore Diameter Change***

	1R		2R		3R	
	T-AT**	F-B	T-AT	F-B	T-AT	F-B
Top	0.0016	0.0009	0.0008	0.0050	0.0010	-0.0004
Middle	0.0008	0.0021	0.0003	0.0022	0.0002	0.0002
Bottom	-0.0001	0.0000	-0.0001	-0.0001	0.0010	-0.0001

	Average Change	
	T-AT	F-B
Top	0.0011	0.0018
Middle	0.0004	0.0015
Bottom	0.0003	-0.0001

Overall average change: 0.0009

Piston Ring End Gap Change

Ring Number	1L	2L	3L	1R	2R	3R	Average
1	0.002	0.002	0.000	0.003	0.004	0.000	0.002
2	0.001	0.001	0.000	0.000	0.002	0.000	0.001
3	0.001	0.001	0.000	0.000	0.001	0.000	0.001
4	0.000	0.000	0.000	0.001	0.002	0.001	0.001
5	0.005	0.060	0.004	0.012	0.009	0.004	0.016
6	0.004	0.047	0.002	0.011	0.004	0.003	0.012
7	0.003	0.039	0.003	0.008	0.003	0.004	0.010

Overall average change: 0.0059

Average Piston Ring Radial Width Change

Ring Number	1L	2L	3L	1R	2R	3R	Average
1	0.0006	0.0001	-0.0002	-0.0003	-0.0013	0.0001	-0.00017
2	0.0001	0.0000	0.0007	0.0000	-0.0002	-0.0052	-0.00077
3	0.0004	0.0004	0.0001	-0.0003	-0.0013	-0.0012	-0.00032
4	0.0002	0.0003	0.0001	-0.0004	-0.0003	-0.0003	-0.00007

Overall average change: -0.0003

Bearing Weight Change

Main Bearings	1	2	3	4	Average
Upper	0.0112	0.013	0.0148	0.0236	0.01565
Lower	0.0288	0.1035	0.0571	0.0628	0.06305

Overall average change: 0.0394

Rod Bearings	1L	2L	3L	1R	2R	3R	Average
Upper	0.0176	0.0224	0.0384	0.0102	0.0222	0.0254	0.0227
Lower	0.0048	0.0043	0.0037	0.0031	0.0022	0.0044	0.0038

Overall average change: 0.0132

*All dimensions are given in inches.
**T-AT=Thrust-Antithrust Direction; F-B= Front-Back Direction.

6V-53T
Test 39
POST TEST ENGINE CONDITION AND DEPOSITS
Lubricant: AL-12634-L

	Cylinder Number						
	1L	2L	3L	1R	2R	3R	Average
Cylinder Liner							
Intake Port Plugging, % restriction	<1	<1	<1	<1	<1	<1	<1
Liner Scuffing, % Area							
Thrust	0.00	28.00	2.00	94.00	46.00	0.00	28.33
Anti-Thrust	6.00	71.00	12.00	61.00	64.00	10.00	37.33
%Total Area Scuffing	3.00	44.50	7.00	77.50	55.00	5.00	32.83
						Overall:	32.83
Bore Polishing, % Area							
Thrust	2.00	2.00	5.00	0.00	2.00	10.00	3.50
Anti-Thrust	5.00	3.00	5.00	2.00	3.00	2.00	3.33
%Total Area Polishing	3.50	2.50	5.00	1.00	2.50	6.00	3.42
						Overall:	16.52
Pistons							
Ring Face Distress, demerits							
No. 1	7.50	8.50	19.00	25.25	13.75	16.50	15.08
No. 2	6.75	21.25	11.25	10.00	10.50	4.00	10.63
No. 3	13.75	36.25	18.75	22.50	23.75	16.25	21.88
No. 4	16.50	26.50	11.25	25.00	26.25	17.50	20.50
						Overall:	17.02
Piston Skirt Rating*							
Thrust	10%SC	35%SC	S	10%SC	S	5%SC	
Anti-Thrust	5%SC	5%SC	S	15%SC	10%SC	10%SC	
Upper Oil Control Ring Expander Force (lbs)	19.4	20.4	20.2	20.4	20.2	20.2	20.133333
Piston WTD Rating**	195	230.75	274.375	230.625	289.125	244.854	244.1215
Ring Sticking***							
No. 1	F	F	F	P	F	F	
No. 2	F	F	F	F	F	F	
No. 3	F	F	F	F	F	F	
No. 4	F	F	F	F	F	F	
Exhaust Valves							
Deposits+							
Head	BHC+	BHC	BHC	AHC	AHC	AHC	
Face	1/4AHC	1/4AHC	1/4AHC	1/4AHC	1/4AHC	1/4AHC	
Tulip	AHC	AHC	AHC	AHC	AHC	AHC	
Stem	#9 Lacquer++	#9 Lacquer	#9 Lacquer	#9 Lacquer	#9 Lacquer	#9 Lacquer	
Surface Condition+++							
Freeness in Guide	F	F	F	F	F	F	
Head	N	N	N	N	N	N	
Face	N	N	N	N	N	N	
Seat	LL	LL	N	LL	LL	LL	
Stem	N	N	N	N	N	N	
Tip	N	N	N	N	N	N	
Other Ratings							
Bearing Surface Condition							
Main Bearings	----------Normal----------						
Rod Bearings	3L connecting rod bearing has copper showing (it was this way after break-in)						
Injector Needles							
Tip Demerits	7.60	7.20	9.00	9.00	8.60	9.00	8.40
Shaft Demerits	1.50	0.90	0.90	0.95	0.00	1.10	0.89

* L=Light, S=Scratches, PM=Plating Melted, N=Normal. SC=Scuffing, B=Burn
** CRC Weighted Total Deposits (0 = least, 900 = most)
*** HS = Hot Stuck, CS = Cold Stuck, P = Pinched, F = Free, N= Normal, CH = Chipped, C = Collapsed
+ HC = Hard Carbon, MC= Medium Carbon, LC=Light Carbon ; the number-letter, prefix indicates carbon depth with 1/4A = least to j = most]
++ The higher the number, the darker the lacquer (0 = lightest, 9= darkest)
+++ F = Free, N = Normal, LW = Light Leakage

6V-53T
Test 39
FUEL INJECTOR TESTS
Fuel: AI-12780-F

	Cylinder Number						
	*1L	2L	3L	1R	2R	3R	Average
Pop-Off Pressure, Psi							
Before Test	144	138	136	132	122	126	133.0
After Test, Before Cleaning	120	128	None	126	135	125	126.8
After Test, After Cleaning	None	130	132	127	131	130	130.0
Spray Pattern							
Before Test	Good	Good	Good	Good	Good	Good	
After Test, Before Cleaning	Good	Good	Poor	Good	Good	Good	
After Test, After Cleaning	Good	Good	Good	Good	Good	Good	
Atomization							
Before Test	Good	Good	Good	Good	Good	Good	
After Test, Before Cleaning	Fair	Good	Poor	Good	Good	Good	
After Test, After Cleaning	Poor	Good	Good	Good	Good	Good	
Leak Down Time, sec.							
Before Test	15.8	15.8	16	17	15.8	16	16.1
After Test, Before Cleaning	15.7	15.05	15.05	15.5	15.5	16+	15.5
After Test, After Cleaning	16+	15.6	16+	16+	15	15.35	15.7
Fuel Pump Calibration (cc/1000 stks)							
Before Test	98	93	95	98	98	98	96.7
After Test, Before Cleaning	97	92	98	97	97	98	96.5
After Test, After Cleaning	97	93	98	98	98	98	97.0

+ Off the Flowmeter scale

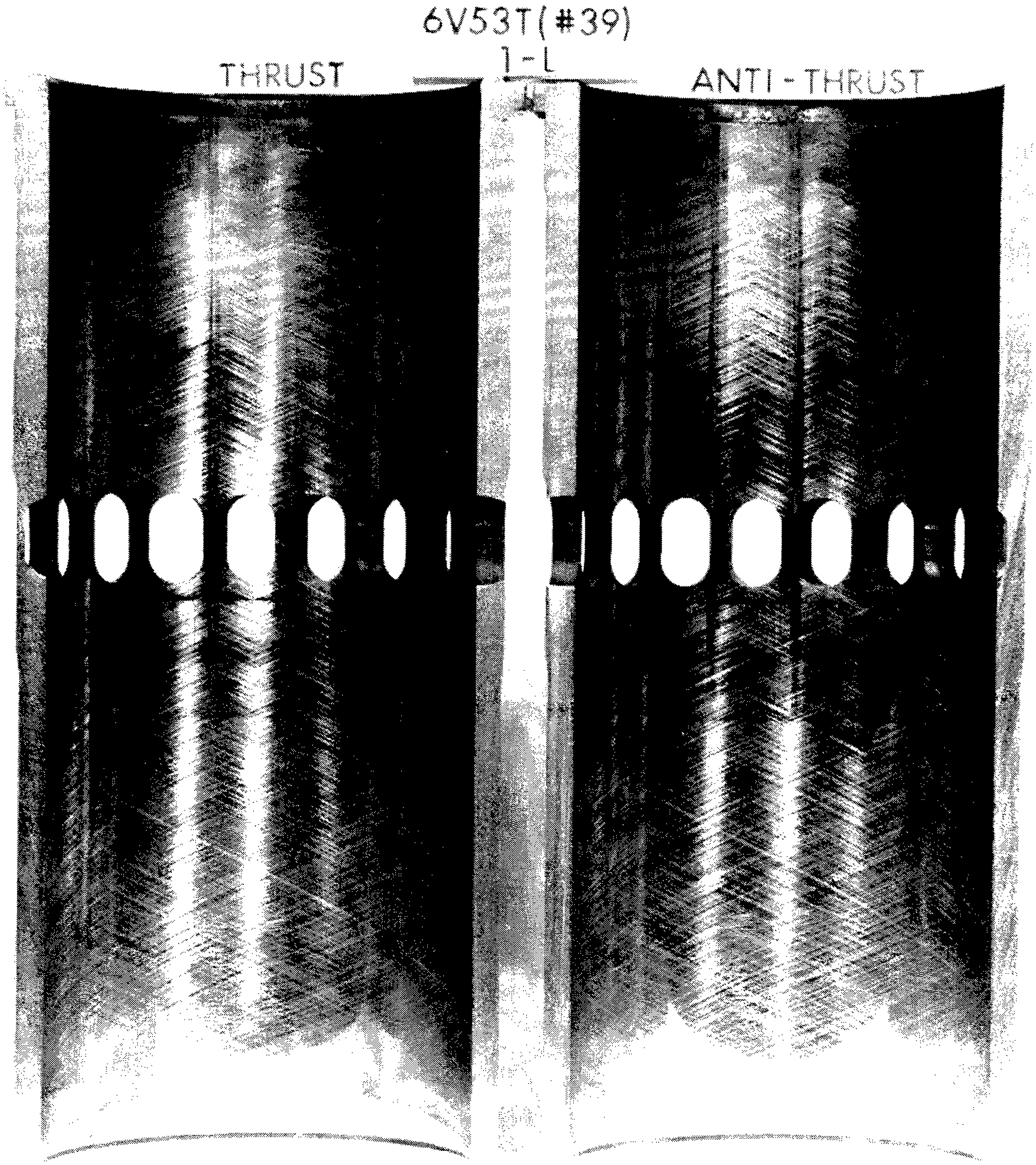


Figure C-8. 6V53T Test 39, Liner 1-L

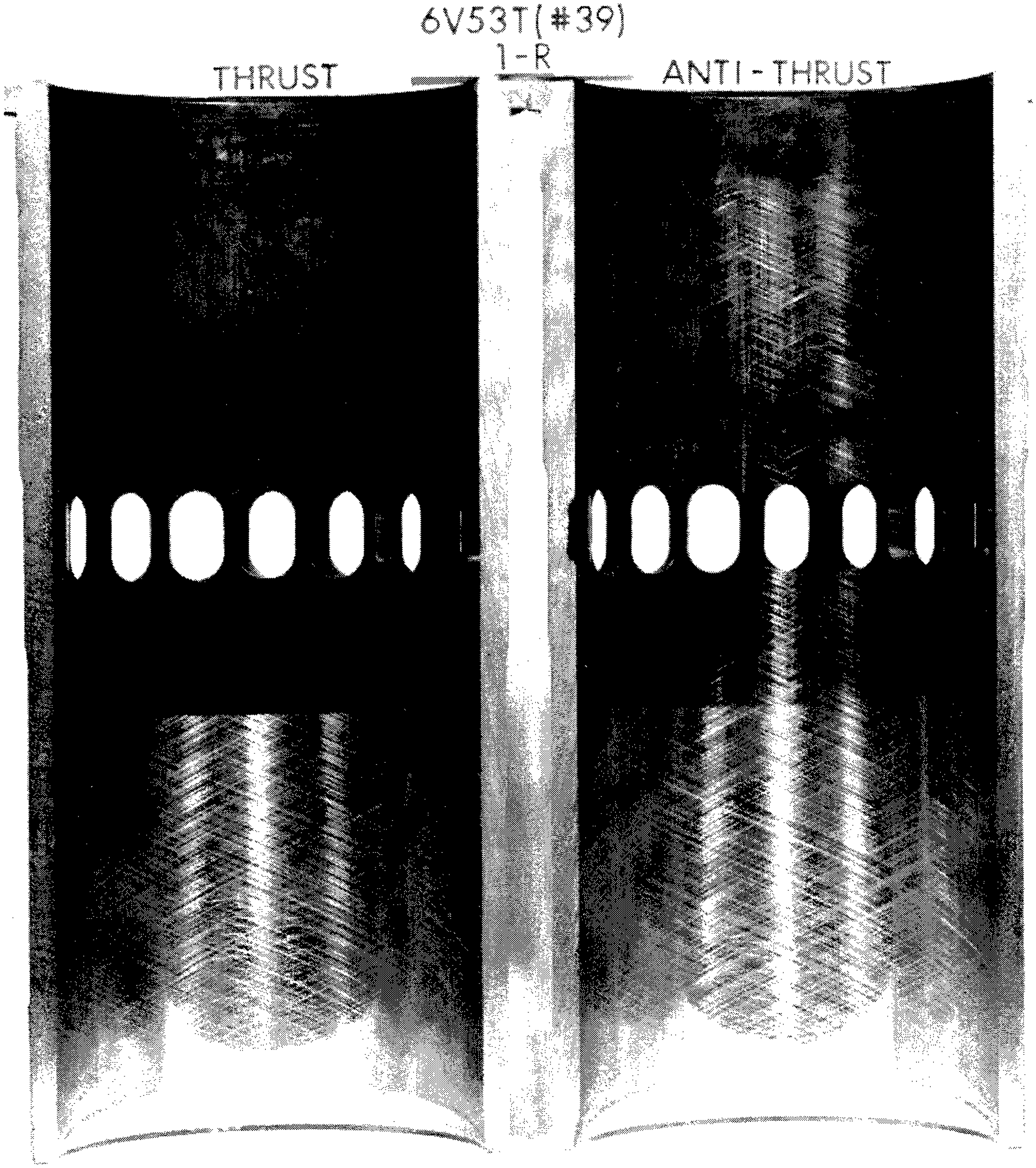


Figure C-9. **<u>6V53T Test 39, Liner 1-R</u>**

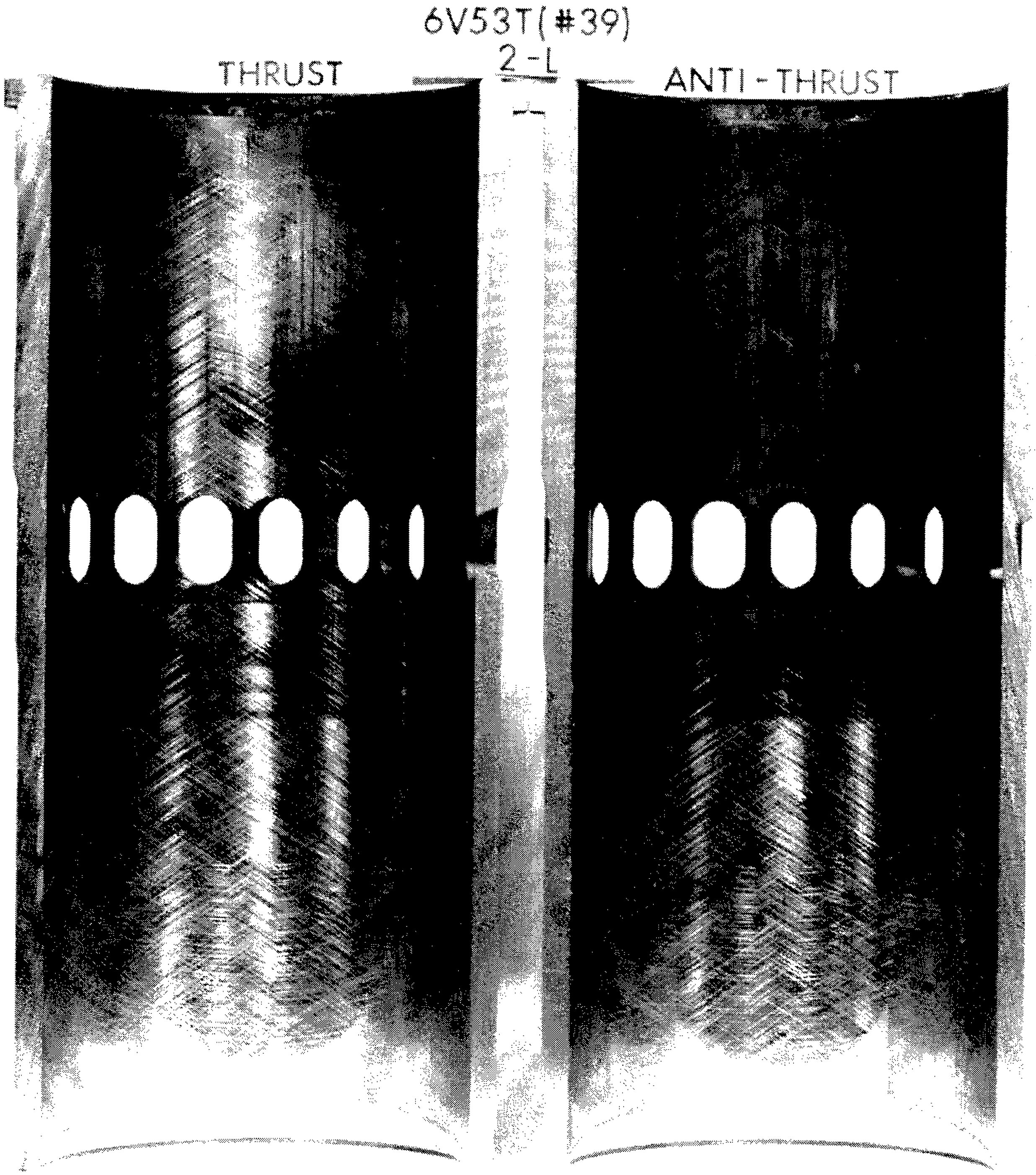


Figure C-10. <u>**6V53T Test 39, Liner 2-L**</u>

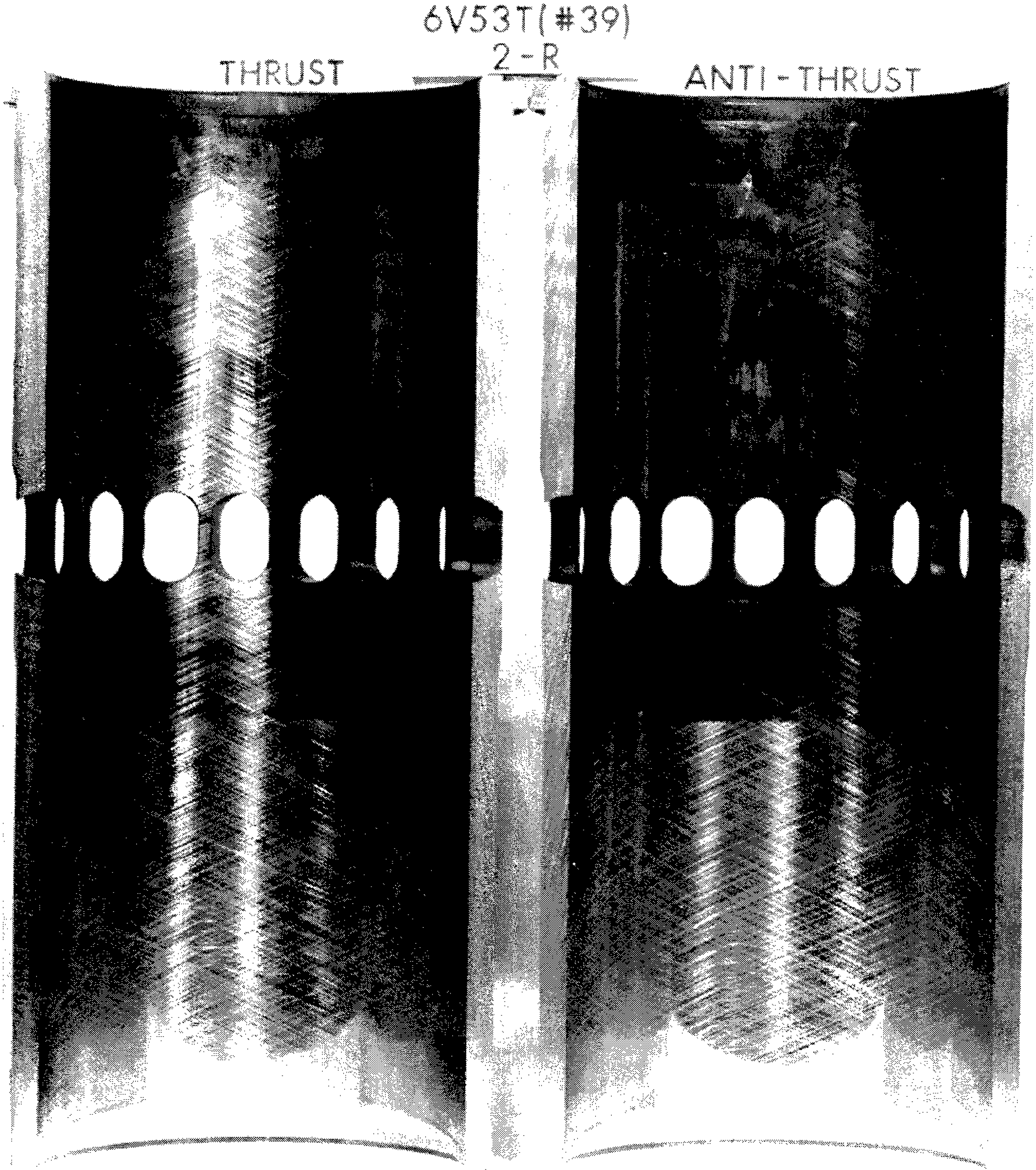


Figure C-11. **<u>6V53T Test 39, Liner 2-R</u>**

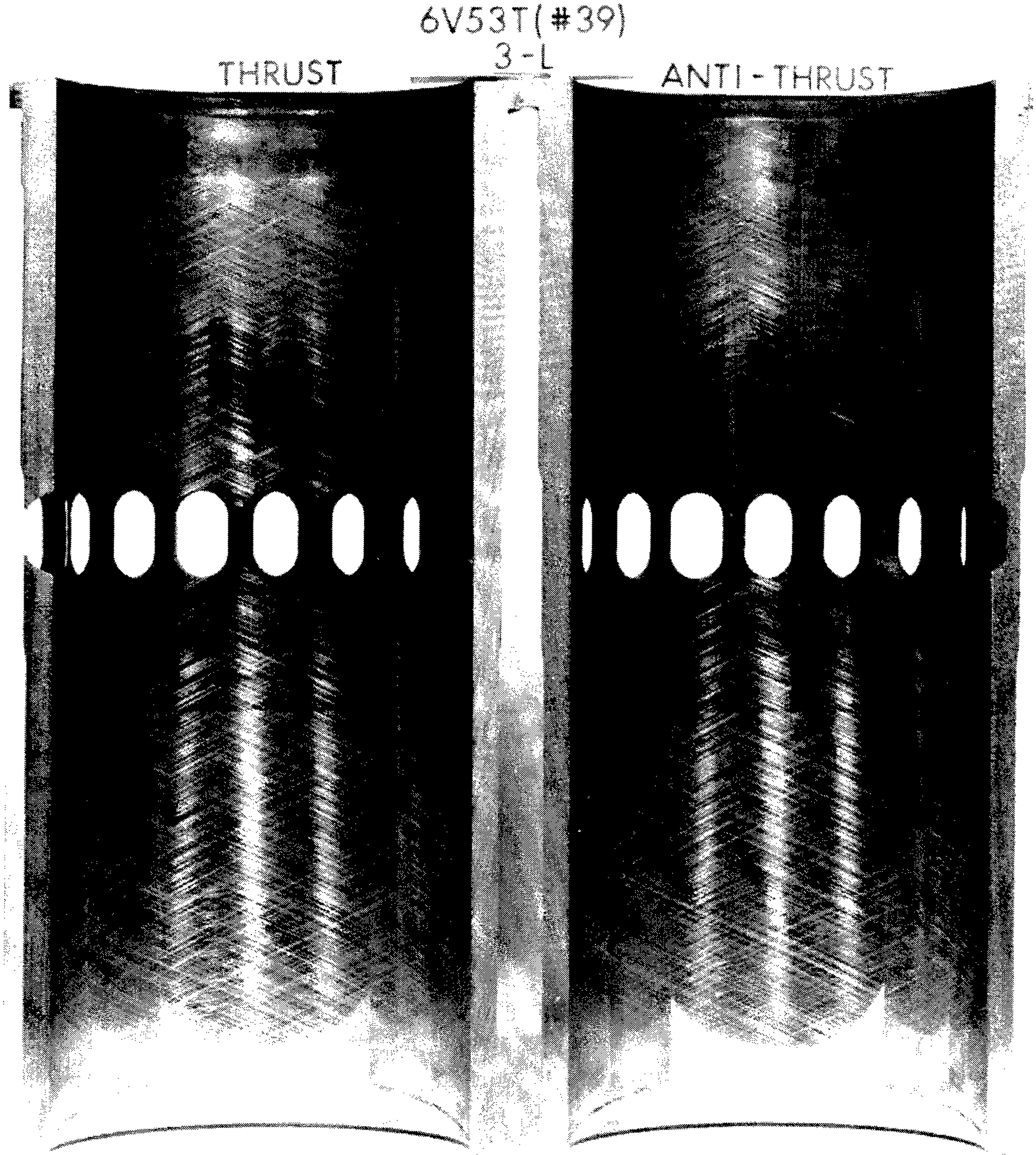


Figure C-12. 6V53T Test 39, Liner 3-L

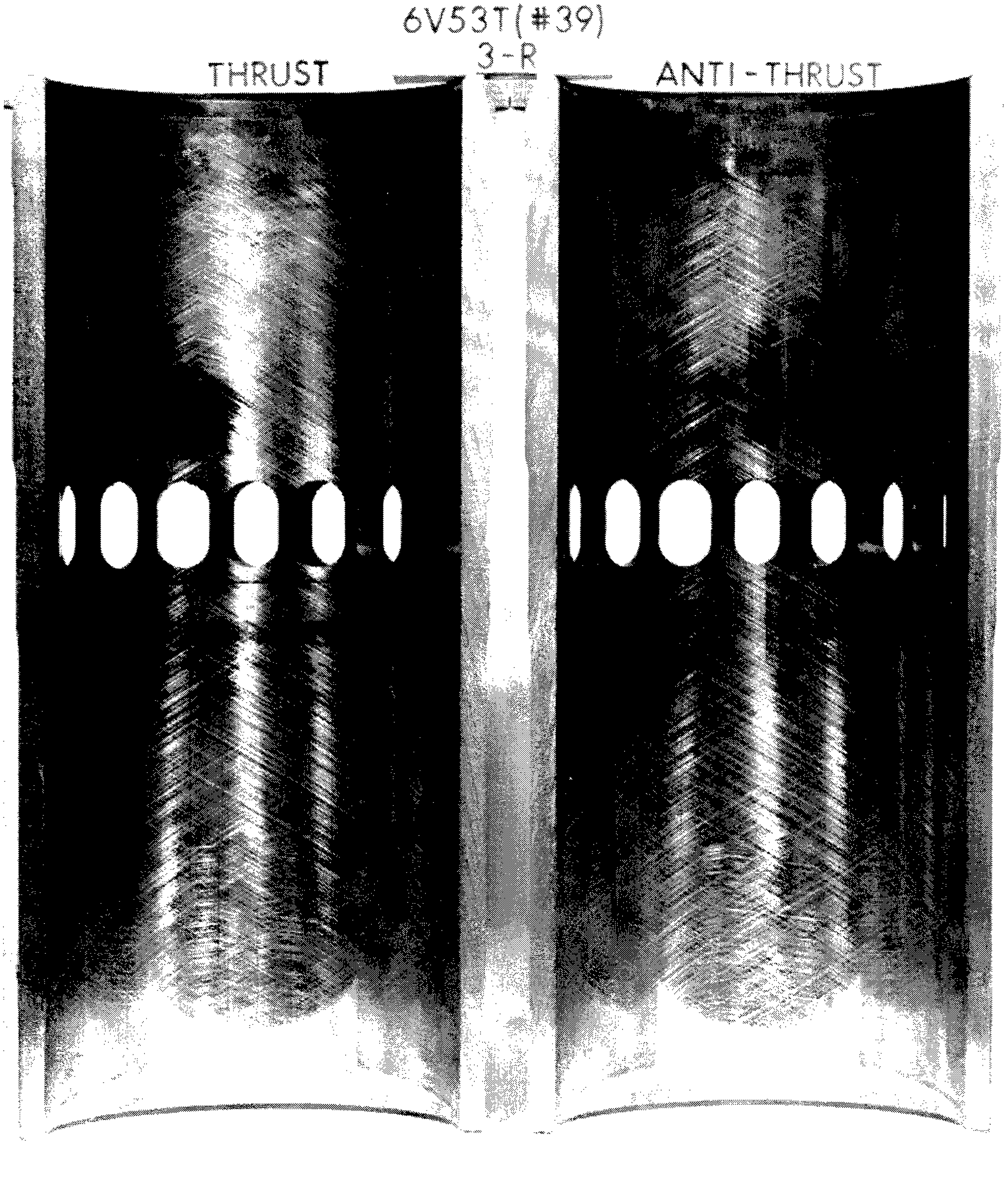


Figure C-13. <u>**6V53T Test 39, Liner 3-R**</u>

Figure C-14. 6V53T Test 39, Piston 1-L-T

Figure C-15. 6V53T Test 39, Piston 1-L-AT

Figure C-16. 6V53T Test 39, Piston 1-R-T

Figure C-17. 6V53T Test 39, Piston 1-R-AT

Figure C-18. 6V53T Test 39, Piston 2-L-T

Figure C-19. 6V53T Test 39 Piston 2-L-AT

Figure C-20. <u>6V53T Test 39, Piston 2-R-T</u>

Figure C-21. <u>6V53T Test 39 Piston 2-R-AT</u>

Figure C-22. <u>6V53T Test 39, Piston 3-L-T</u>

Figure C-23. <u>6V53T Test 39, Piston 3-L-AT</u>

Figure C-24. 6V53T Test 39, Piston 3-R-T

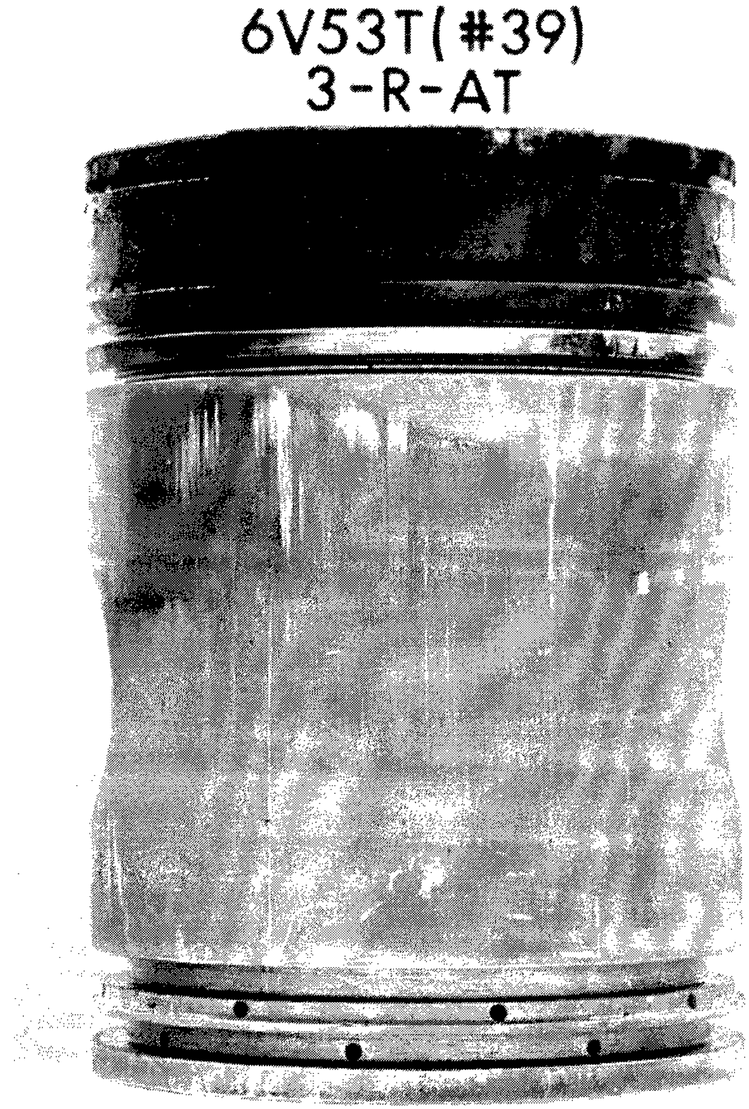


Figure C-25. 6V53T Test 39, Piston 3-R-AT

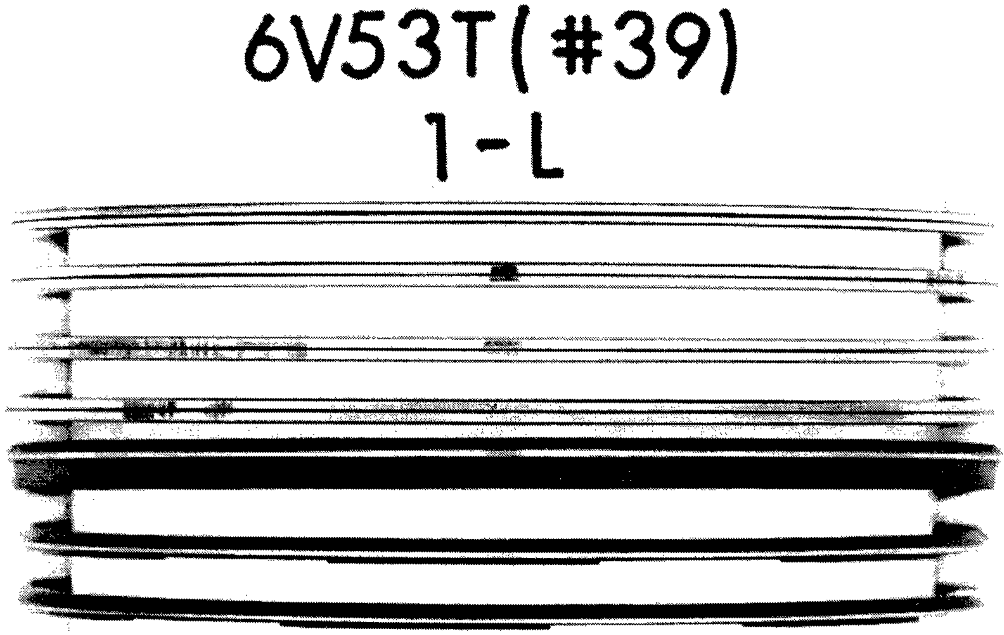


Figure C-26. 6V53T Test 39, Cylinder 1-L, Rings

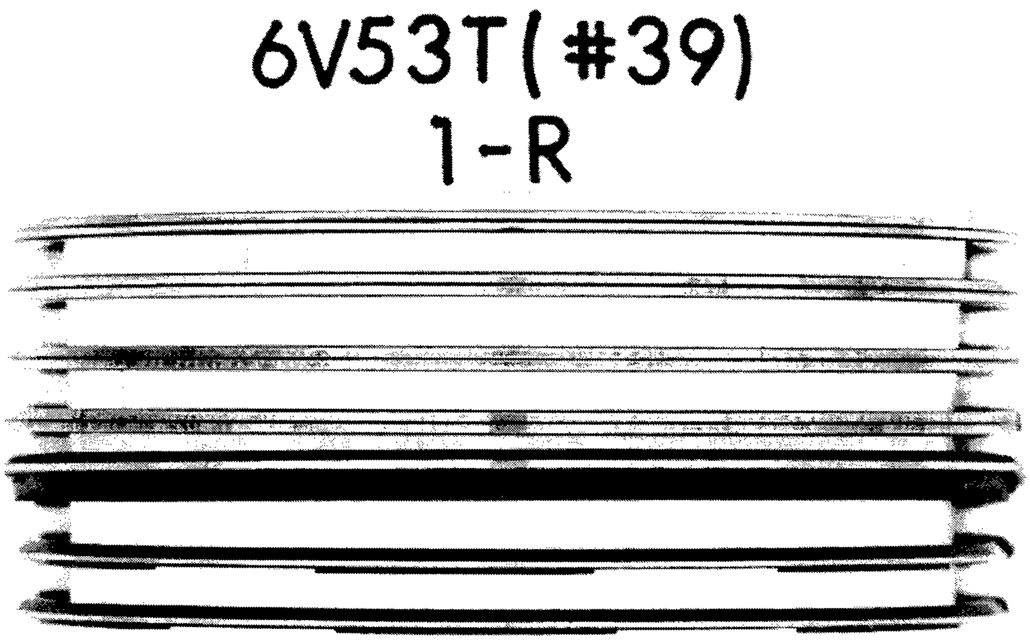


Figure C-27. 6V53T Test 39, Cylinder 1-R, Rings

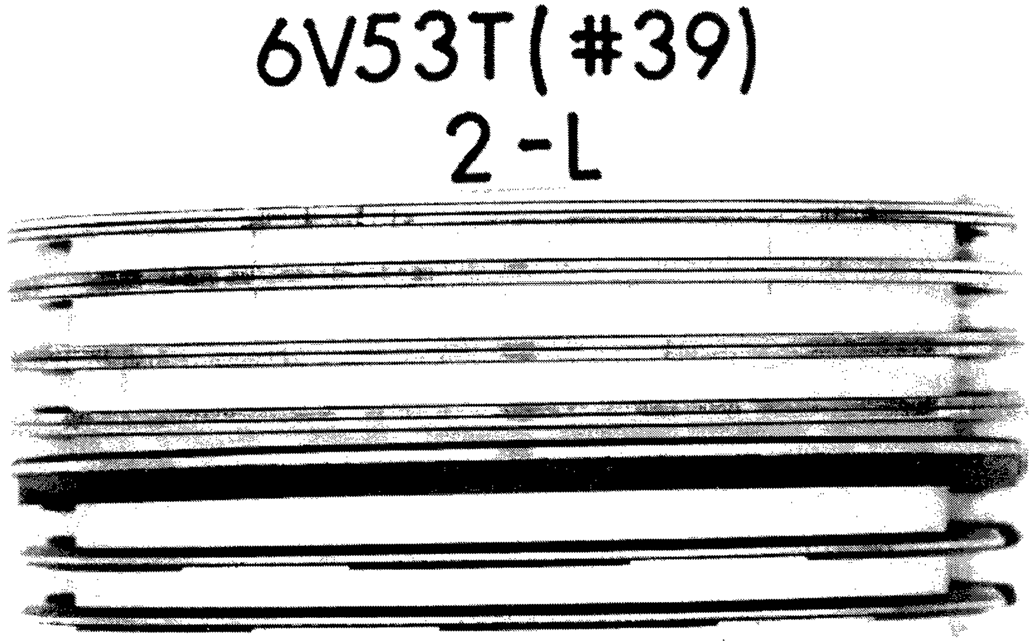


Figure C-28. 6V53T Test 39, Cylinder 2-L, Rings

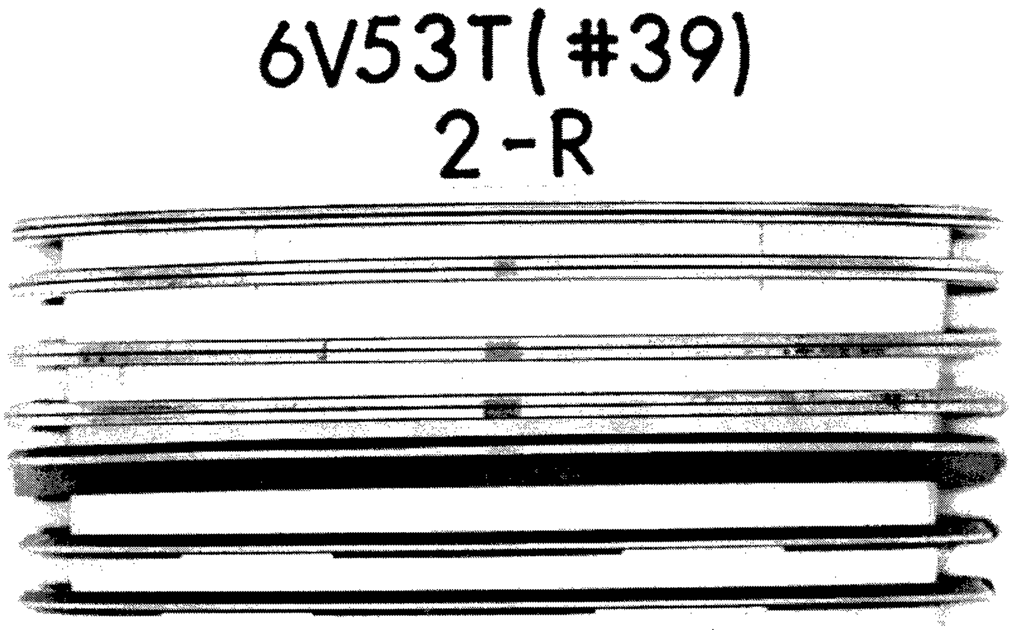


Figure C-29. 6V53T Test 39, Cylinder 2-R, Rings

Figure C-30. 6V53T Test 39, Cylinder 3-L, Rings

Figure C-31. 6V53T Test 39, Cylinder 3-R, Rings

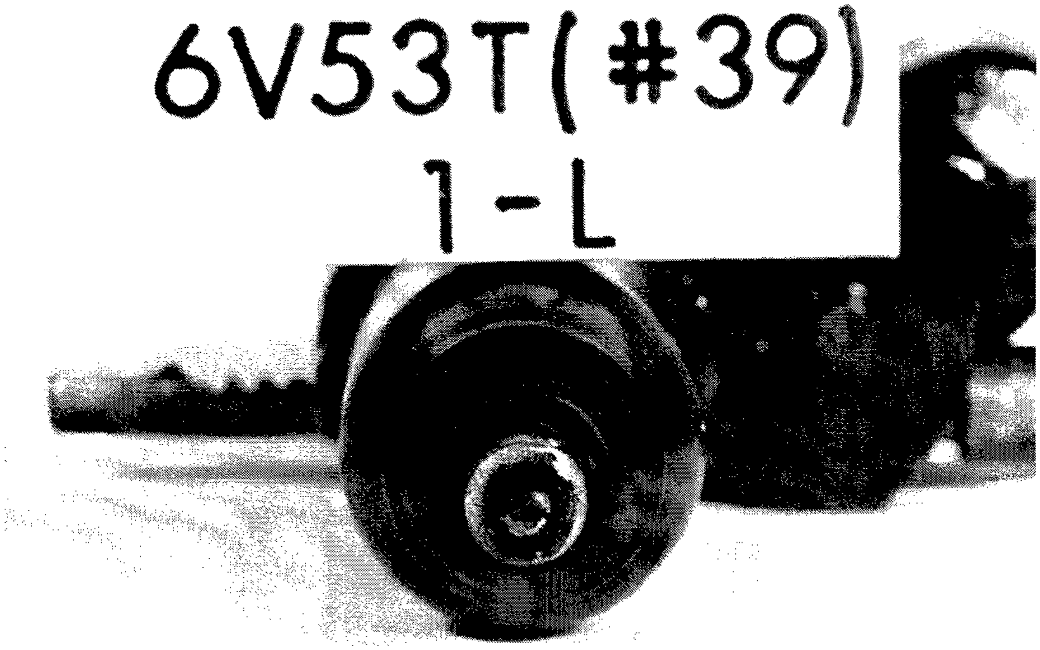


Figure C-32. 6V53T Test 39, Injector 1-L

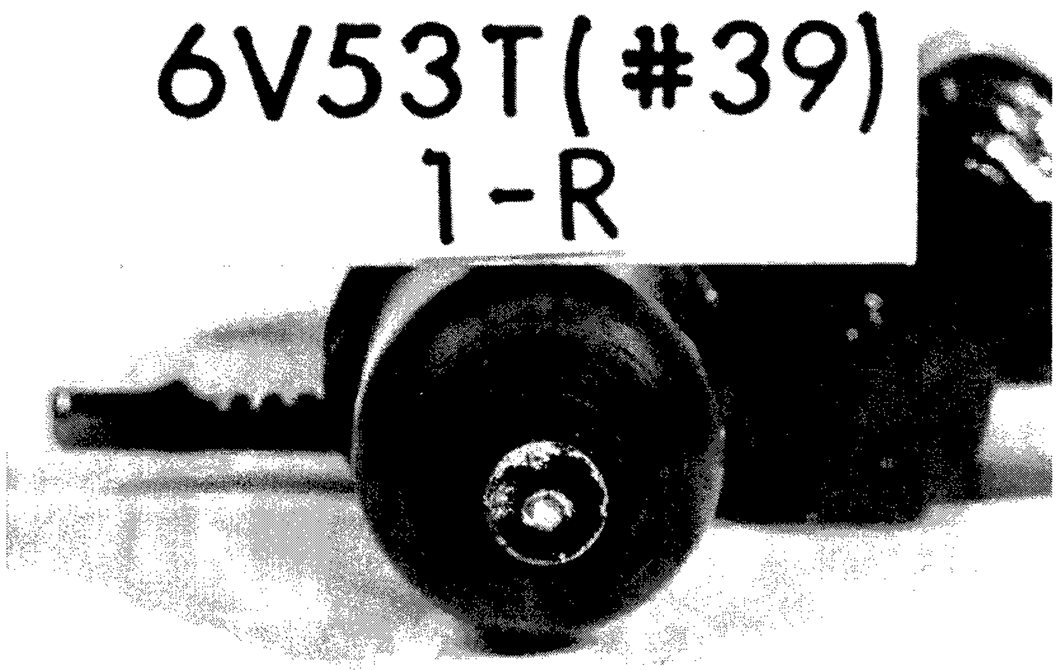


Figure C-33. 6V53T Test 39, Injector 1-R

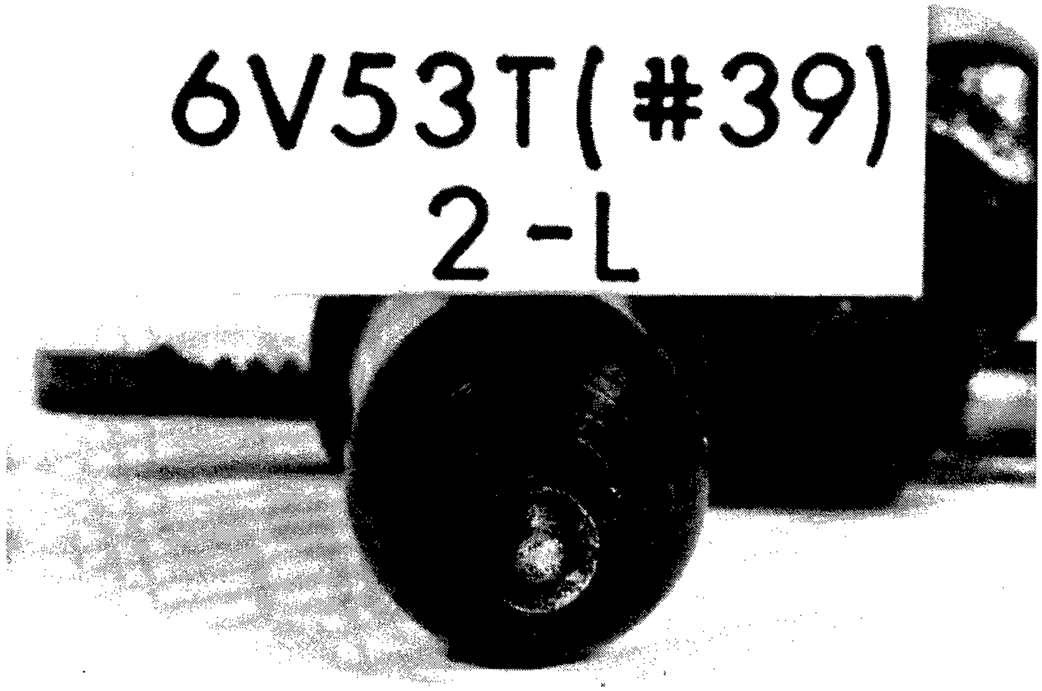


Figure C-34. **6V53T Test 39, Injector 2-L**

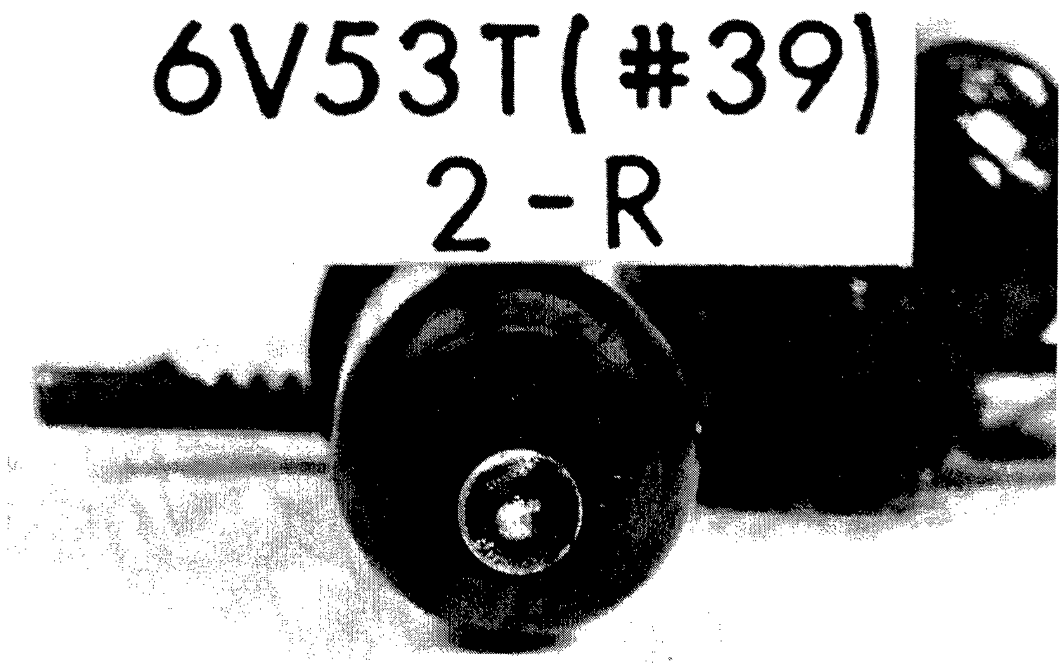


Figure C-35. **6V53T Test 39, Injector 2-R**

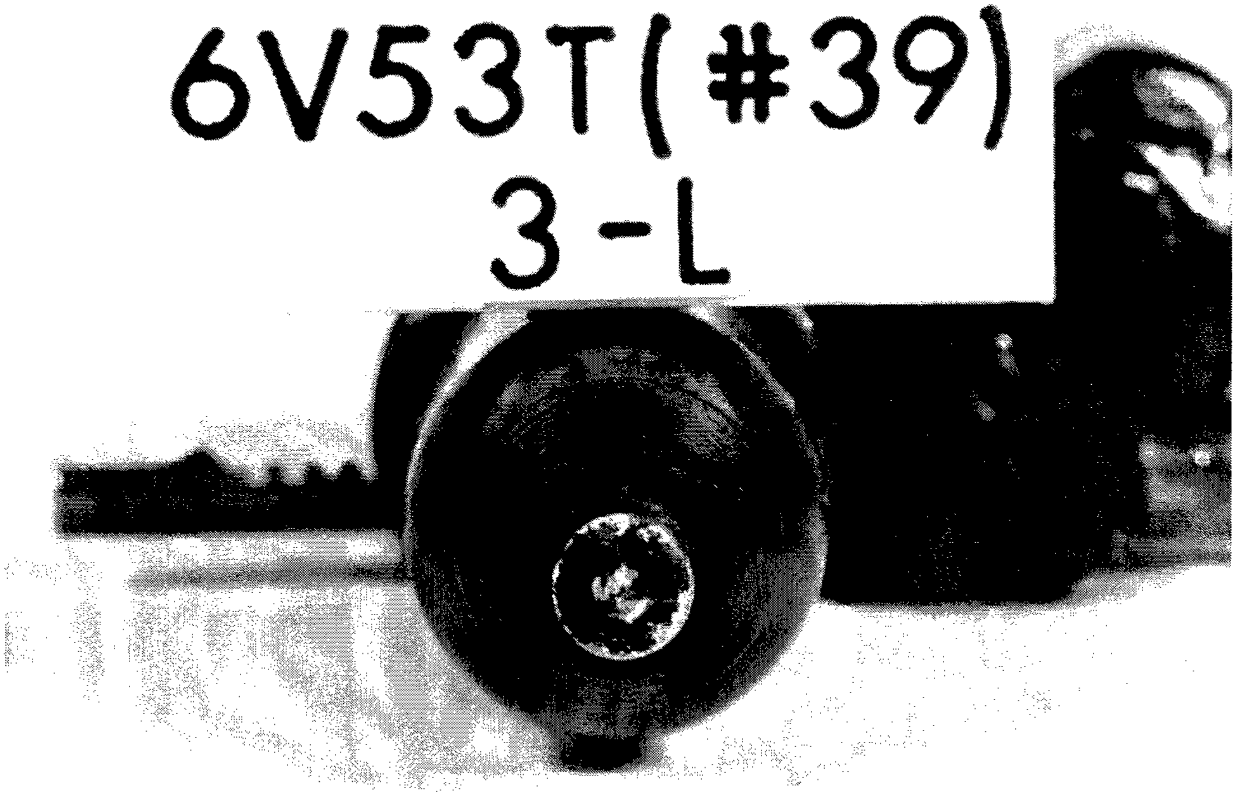


Figure C-36. 6V53T Test 39, Injector 3-L

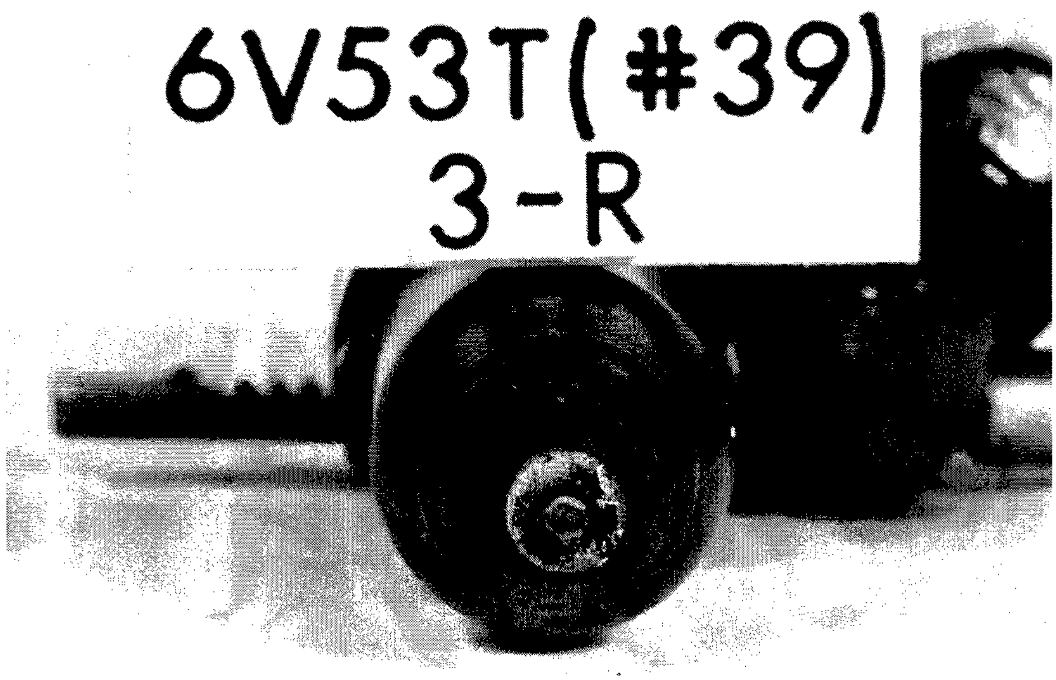


Figure C-37. 6V53T Test 39, Injector 3-R

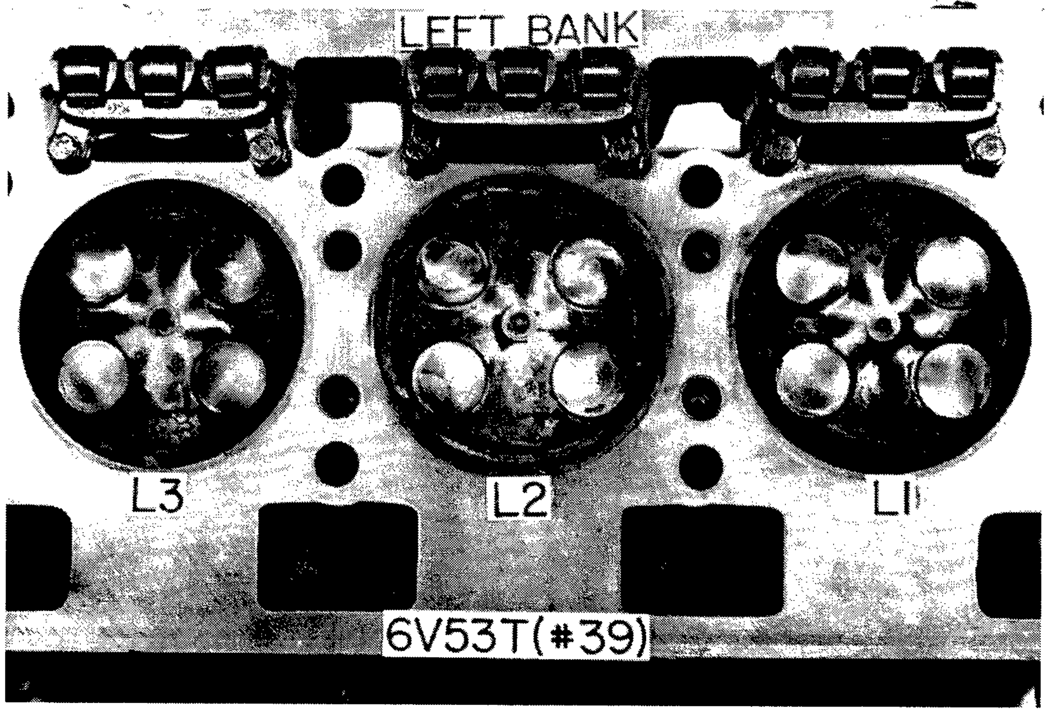


Figure C-38. 6V53T Test 39, Left Bank

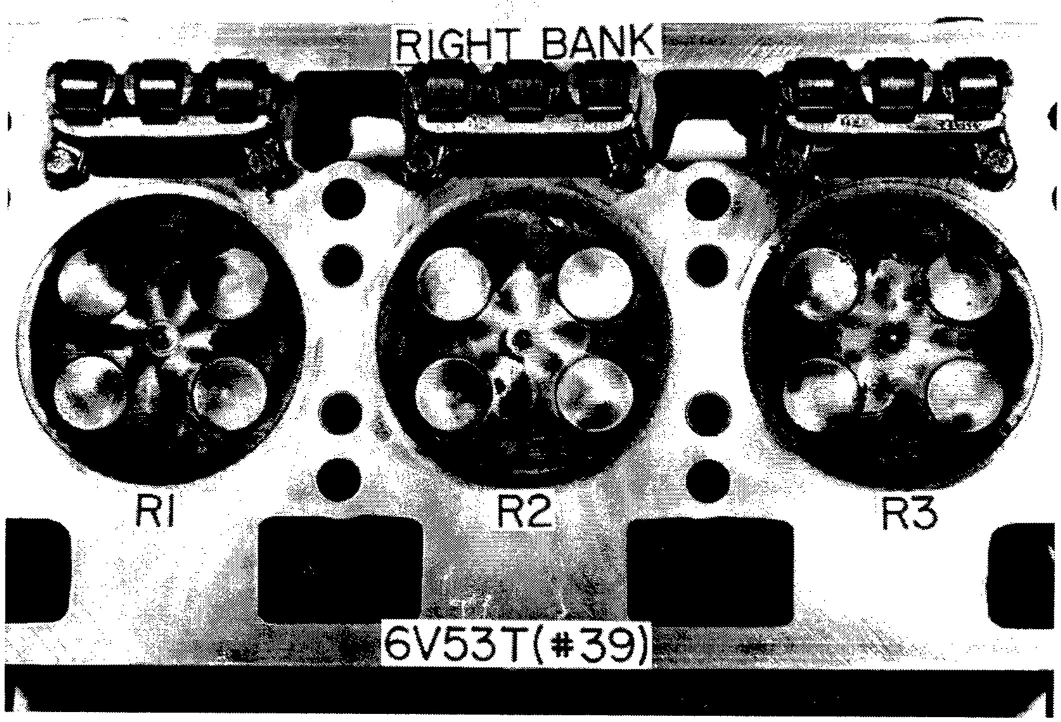


Figure C-39. 6V53T Test 39, Right Bank

APPENDIX D
6V53T Blended JP-8/Used Oil Fuel Evaluation –Test 60

Evaluation of JP-8 Blended with Used Oil in a 6V-53T Engine

Test Lubricant: REO-203 (AL-24867-L/AL-20241)
Test Fuel: Blended JP-8 and Used Oil (AL-24855-F)
Test No.: Test 60
Date: May 1997

Conducted For

U.S. Army Tank-Automotive Research, Development and Engineering Center
Logistics Equipment Directorate
Fort Belvoir, Virginia 22060-5606

By

TARDEC Fuels and Lubricants Research Facility (SwRI)
Southwest Research Institute
P.O. Drawer 28510
San Antonio, Texas 78228-0510

6V-53T
TEST 60
ENGINE REBUILD MEASUREMENTS*
BLOCK NUMBER: 3

	Minimum	Maximum	Average	Specified Limits
Cylinder Block Bore				
Inside Diameter (Bottom)	4.3568	4.3585	4.3576	4.3565 - 4.3575
Out of Round	0.0001	0.0023	0.0012	0.0015 Max
Taper	0.0000	0.0011	0.0006	0.0015 Max
Cylinder Liners (Installed)				
Inside Diameter	3.8753	3.8767	3.876	3.8752 - 3.8767
Out of Round	0.0000	0.0006	0.0003	0.0015 Max
Taper	0.0000	0.0013	0.0006	0.0015 Max
Piston Diameter (at skirt)	3.8678	3.8691	1.8684	3.8669 - 3.8669
Piston Skirt to Cylinder Liner Clearance	0.0062	0.0087	0.0074	0.0061 - 0.0098
Compression Rings				
Gap (No. 1, Fire Ring)	0.010	0.031	0.020	0.020 - 0.046
Gap (Nos. 2,3,4)	0.024	0.031	0.028	0.020 - 0.036
Ring-to-Groove Clearance				
Top (No. 1, Fire Ring)	0.003	0.004	0.004	0.003 - 0.006
No. 2, Compression Ring	0.007	0.008	0.008	0.007 - 0.010
No. 3 and 4, Compression Rings	0.006	0.006	0.006	0.005 - 0.04
Oil Control Rings, Nos. 5, 6, 7				
Gap	0.008	0.019	0.014	0.010 - 0.025
Ring-to-Groove Clearance	0.002	0.003	0.002	0.0015 - 0.0055
Piston Pin				
Pin-to-Piston Bushing Clearance	0.0026	0.0031	0.0028	0.0025 - 0.0034
Pin-to-Connecting Rod Bushing Clearance	0.0012	0.0014	0.0013	0.0010 - 0.0019
Connecting Rod Bearing--to Journal Clearance	0.0019	0.0028	0.0024	0.0011 - 0.0041
Main Bearing-to-Journal Clearance	0.0039	0.0045	0.0042	0.0010 - 0.0040
Camshaft Bearing-to-Journal Clearance	0.005	0.006	0.006	0.0045 - 0.0060

* Measurements are in inches.

6V-53T
Test 60
Operating Conditions Summary
Block Number: 3

	Maximum Power Mode (2800 RPM)		Maximum Torque Mode (2200 RPM)	
	Mean	Standard Deviation	Mean	Standard Deviation
Engine Speed, rpm	2800.9	2.2	2199	8.9
Torque, ft-lb	488.8	24.2	557.5	22.2
Fuel Consumption, lb/hr	106.2	3.3	89.9	3.2
Observed Power, Bhp	260.7	12.9	233.4	9.3
BSFC, lb/Bhp-hr	0.41	0.001	0.39	0.0064
Temperatures, °F				
Exhaust before Turbo	957.9	26.9	956.4	34.2
Exhaust after Turbo	758.2	14.9	785.1	19.5
Water Jacket Inlet	161.6	4.8	161.2	5.3
Water Jacket Outlet	169	4.9	169.2	4.2
Oil Sump	227.5	4.2	220.9	5.6
Fuel at Filter	95.2	3.4	93.7	3.2
Inlet Air	89.5	4.3	89.5	4.6
Airbox	241.4	4.7	205.1	6.3
Pressures				
Exhaust before Turbo, psi	12.7	0.5	8.4	0.5
Exhaust after Turbo, in. Hg	15.2	1.5	7.4	1.8
Compressor Discharge, psi	14.5	0.7	11	0.8
Blower Discharge, psi	18.5	0.7	11.2	0.6
Oil Gallery, psi	45.6	0.8	41.9	1.6
Intake Vacuum, in. H_2O	7.5	0.4	4.6	0.3
Ambient Conditions				
Dry Bulb Temperature, °F	78.7	5.8	78.3	5.2
Wet Bulb Temp., °F	68.8	3.7	69	3.5
Barometric Pressure, in. Hg	29.1	0.8	29.1	0.1

6V-53T
Test 60

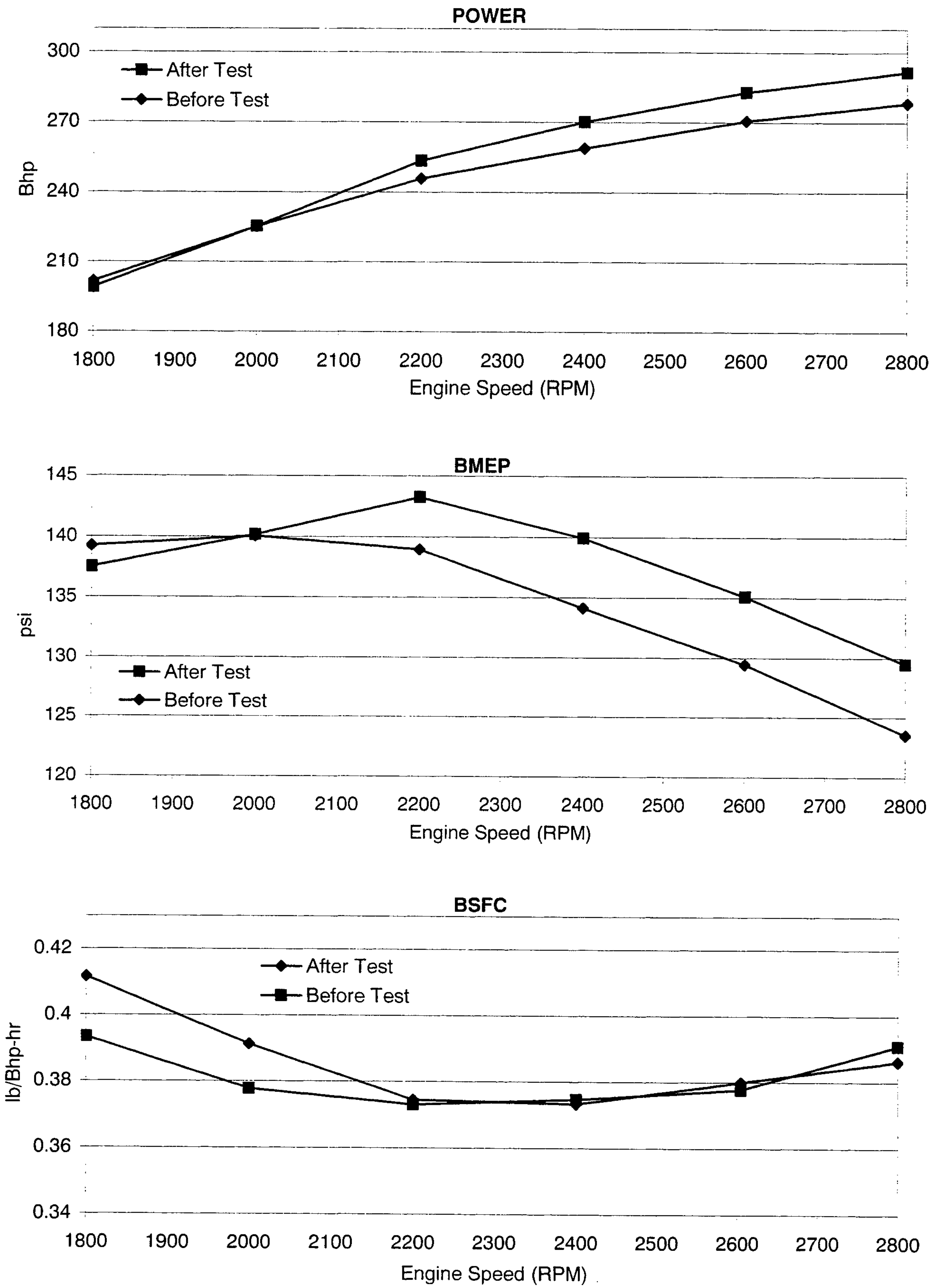


Figure D-1. Full Load Performance

6V-53T
Test 60
FUEL ANALYSIS
Fuel: AL-24855-F*

Property		ASTM Method	AL-24647-F	AL-24855-F
Gravity at 60°F		D 287	43.2	
Distillation, °C	IBP	D 86	153	
	10%	D 86	174	
	30%	D 86	190	
	50%	D 86	206	
	70%	D 86	225	
	80%	D 86	237	
	90%	D 86	266	
	End Point	D 86	287	
	Recovered, vol%	D 86	93.9	
	Residue, vol%	D 86	6.1	
Flash Point, °C		D 92	43	
Cloud Point, °C		D 5773	Not obtainable	
Cetane Number		D 613	46.2	
Kinematic Viscosity at 40°C, cSt		D 445	1.6	
Cu Corrosion, at 100°C		D 130	lb	
Total Acid Number		D 664	0.22	
Aromatics, vol%		D 1319	17.5⁺	
Sulfur, mass%		D 2622	0.08	
Net Heat of Combustion, Btu/lb (MJ/kg)		D 240	18,578 (43.21)	
Carbon, mass%		D 5291	85.81	
Hydrogen, wt%		D 5291	13.72	
Particulate Contamination, mg/L		D 5452	14.2*	
Existent Gum, mg/100 mL		D 381	3146.7	
Carbon Residue (10% Bottoms)		D 524	1.07	
Ash, wt%		D 482	0.064	
Accelerated Stability, mg/100mL		D 2274	0.2**	
Interfacial Tension, dynes/cm		D 971	20.8	
Lubricity:	HFRR, mm	ISO	0.46	
	BOCLE, mm	D 5001	0.71	
	SLWT, kg	ARMY	4150⁺⁺	
Water Content, ppm		D 4928	384	
Elemental, ppm	Ca	D 5185	143	163
	Mg	D 5185	17	19
	P	D 5185	62	66
	Zn	D 5185	81	88
	Ag	D 5185	<1	
	Al	D 5185	1	
	B	D 5185	6	
	Ba	D 5185	<1	
	Cr	D 5185	1	
	Cu	D 5185	6	
	Fe	D 5185	8	
	Mo	D 5185	6	
	Mn	D 5185	<1	
	Ni	D 5185	<1	
	Pb	D 5185	<1	
	Sb	D 5185	<1	
	Si	D 5185	3	
	Sn	D 5185	<1	
	Na	D 5185	4	

* Most of the analysis was performed using AL-24647-F, a typical JP-8 fuel blended with 7.5% used oil. Al-24855-F was tested for several wear metals to confirm that the blend is similar to AL-24647-F.

** Soot is visible on both the control and test filters

⁺ Soot came down column and olefin and aromatic separation was not definitive

⁺⁺ Increased chatter during non-scuffing

6V-53T
Test 60
ANALYSIS OF USED OIL FOR FUEL BLEND*
Composite Used Oil: AL-24627-L and AL-24644-L

Property		ASTM Method	AL-24627-L	AL-24644-L**
Viscosity at 40°C, cSt		D 445	82.19	82.19
Flash Point, °C		D 92	207	ND***
Tan		D 664	2.51	ND
Water Content, ppm		D 4928	1910	1760
Pentane Insoluables, wt%		D 893B	0.04	0.05
Toluene Insoluables, wt%		D 893B	0.03	0.04
Gravity at 60°F		D 287	27.8	27.8
Sulfur, wt%		X-Ray	0.6	0.6
Chlorine, ppm		X-Ray	<200	<200
Soot, wt%		TGA	0.5	0.5
Sulfated Ash, wt%		D 874	0.89	ND
Elemental, ppm	Ca	D 5185	1933	1947
	Mg	D 5185	212	210
	P	D 5185	8.78	879
	Zn	D 5185	1004	1013
	Ag	D 5185	<1	<1
	Al	D 5185	12	12
	B	D 5185	85	86
	Ba	D 5185	3	3
	Cr	D 5185	10	10
	Cu	D 5185	67	67
	Fe	D 5185	96	95
	Mo	D 5185	75	75
	Mn	D 5185	3	3
	Ni	D 5185	3	3
	Pb	D 5185	20	21
	Sb	D 5185	<1	<1
	Si	D 5185	45	45
	Sn	D 5185	8	8
	Na	D 5185	15	15

* Analysis was performed on used oil taken from vehicles at Ft. Hood, TX (Letter Report No. TFLRF-97-001).
** Oil was filtered (25 micron Fleetguard FF-202 fuel filter) prior to analysis.
*** ND = Not Determined

6V-53T
Test 60
LUBRICANT ANALYSIS
Lubricant: AL-24867-L/AL-20241-L

	ASTM Test Method	Test Time, Hours												
		0	20	40	60	80	100	120	140	160	180	200	220	240
Kinematic Viscosity at 40°C (104°F) cSt	D 445	103.31	----	----	*NES	----	----	111.67	----	----	111.52	----	----	111.43
Kinematic Viscosity at 100°C (212°F) cSt	D 445	11.81	12.02	12.19	12.3	12.29	12.31	12.49	12.14	12.19	12.5	12.46	12.59	12.5
Total Acid Number mg KOH/g	D 664	2.68	----	----	2.88	----	----	3.55	----	----	3.13	----	----	3.04
Total Base Number mg KOH/g	D 4739	4.85	----	----	4.67	----	----	4.63	----	----	4.8	----	----	4.42
Pentane B Insolubles wt%	D 893	----	----	----	----	----	----	0.37	----	----	----	----	----	0.56
Toluene B Insolubles wt%	D 893	----	----	----	----	----	----	0.26	----	----	----	----	----	0.43

* NES - Not Enough Samples

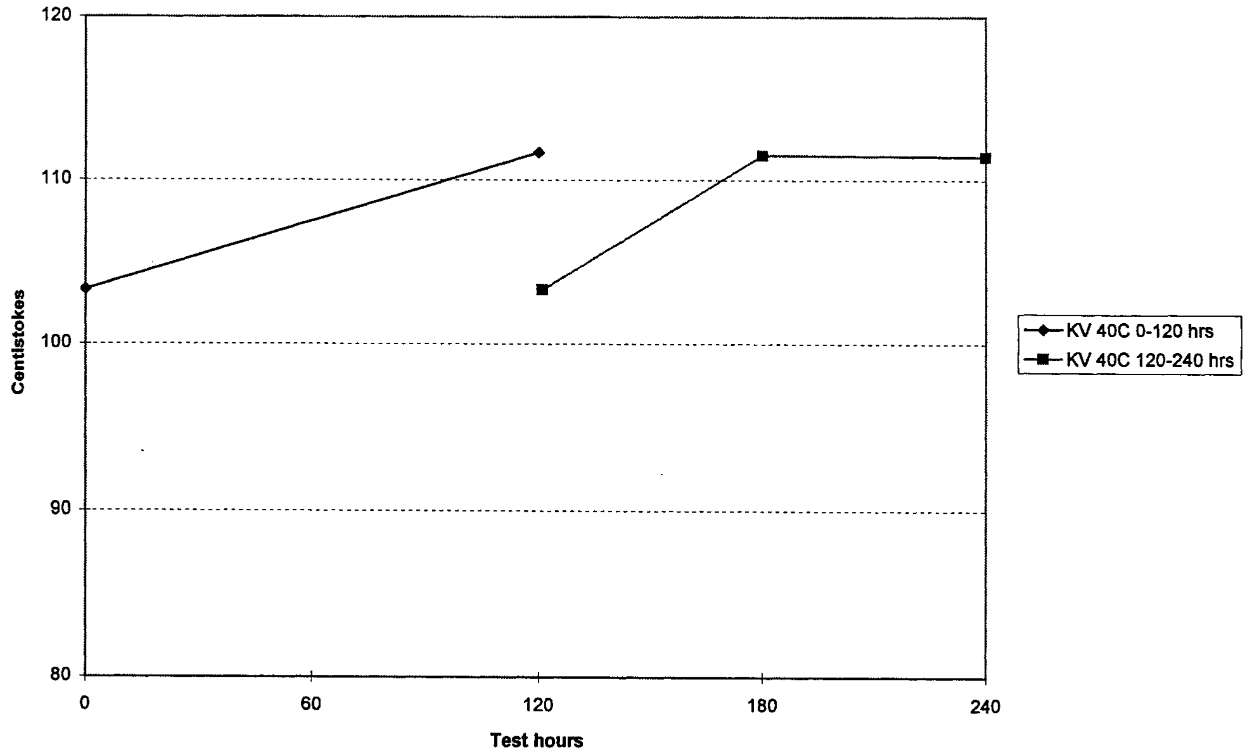


Figure D-2. <u>**Kinematic Viscosity at 40°C**</u>

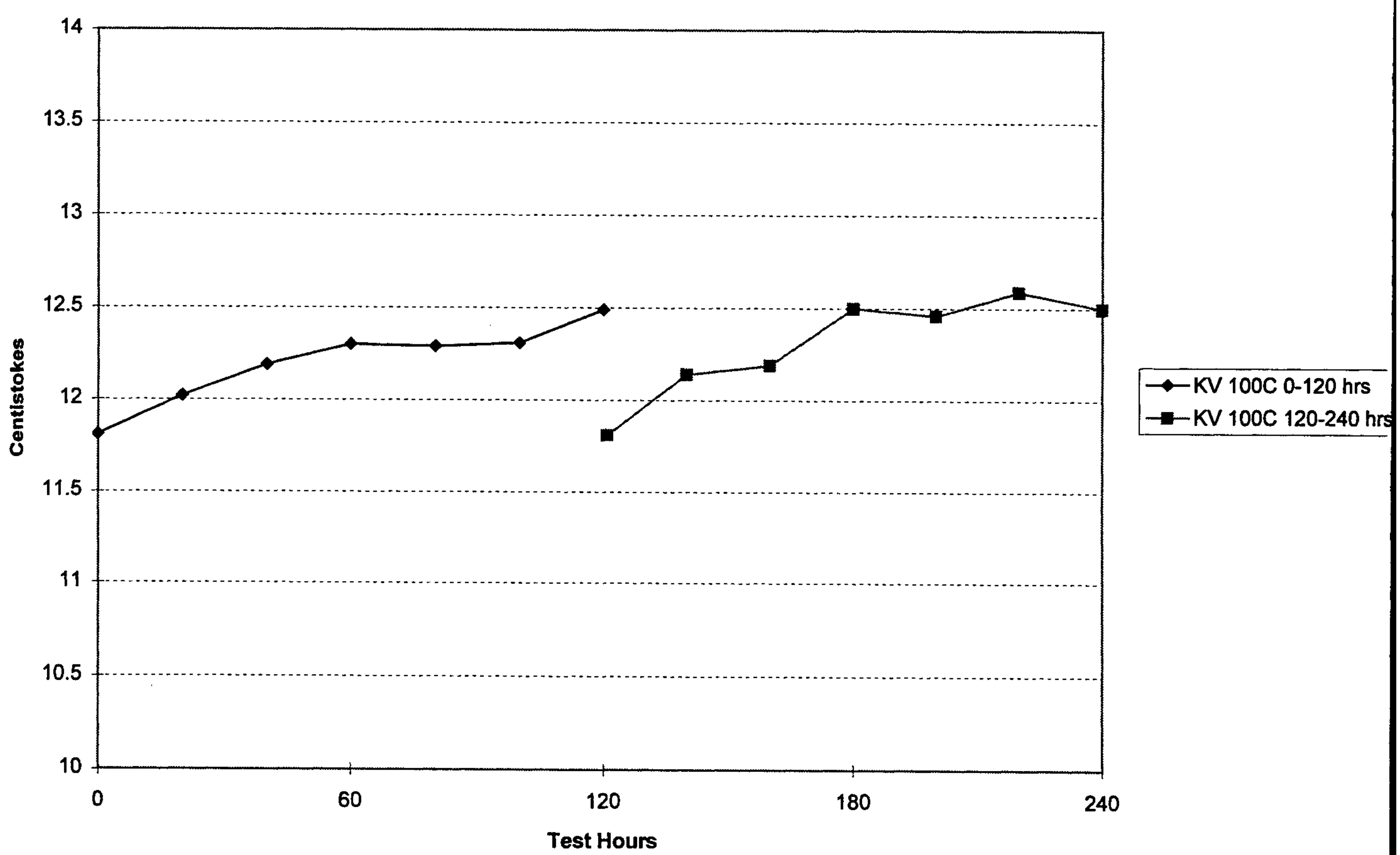


Figure D-3. <u>**Kinematic Viscosity at 100°C**</u>

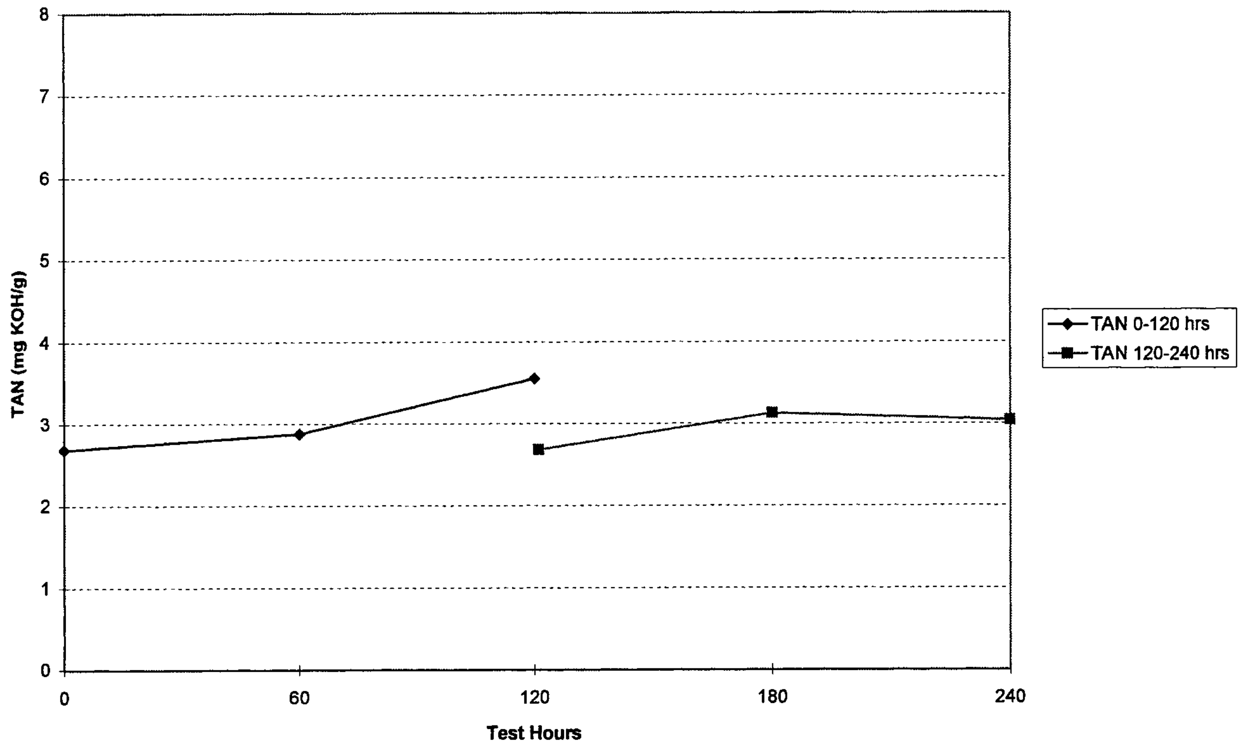


Figure D-4. Total Acid Number

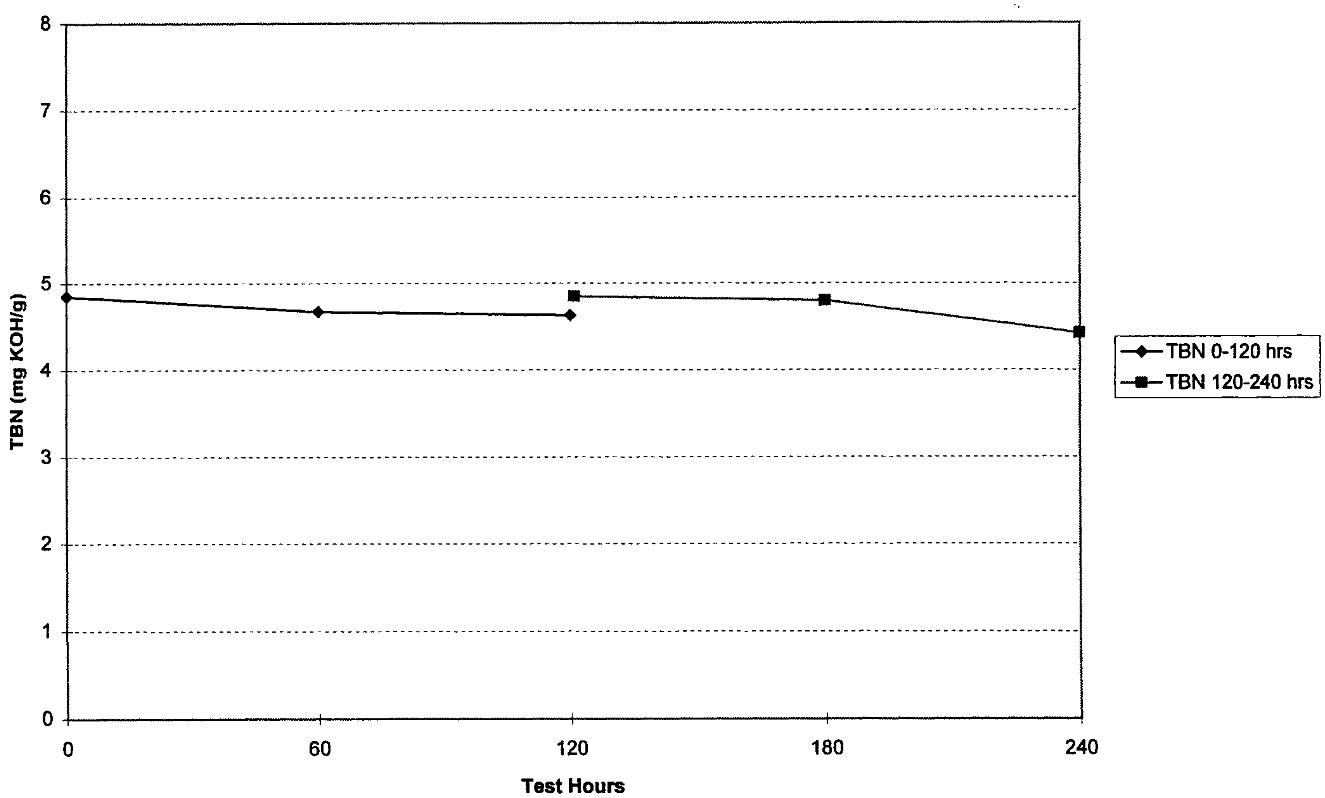


Figure D-5. Total Base Number

6V-53T
Test 60
TOTAL CONSUMPTION AND WEAR METALS BY ICP
Lubricant: AL-24867-L/AL-20241-L (REO-203)

Test Time, Hours	Oil Consumed, lb	Cumulative Oil Consumed	Wear Metals, ppm Fe	Cu	Pb
0	0		21	6	1
Break-in	---		60	25	3
20	6.99	6.99	64	12	1
40	19.54	26.53	47	11	1
60	20.42	46.95	45	10	2
80	19.63	66.58	48	11	3
100	13.6	80.18	55	11	2
120	14.99	95.17	54	10	2
140	11.98	107.15	22	3	1
160	20.85	128.00	60	6	1
180	14.28	142.28	145	9	2
200	20.71	162.99	113	9	3
220	19.74	182.73	125	12	3
240	13.76	196.49	115	10	1

Total oil consumed: 196.49 lb
Average oil consumption rate: 0.819 lb/hr

NOTE: Oil was changed at 120 hours.

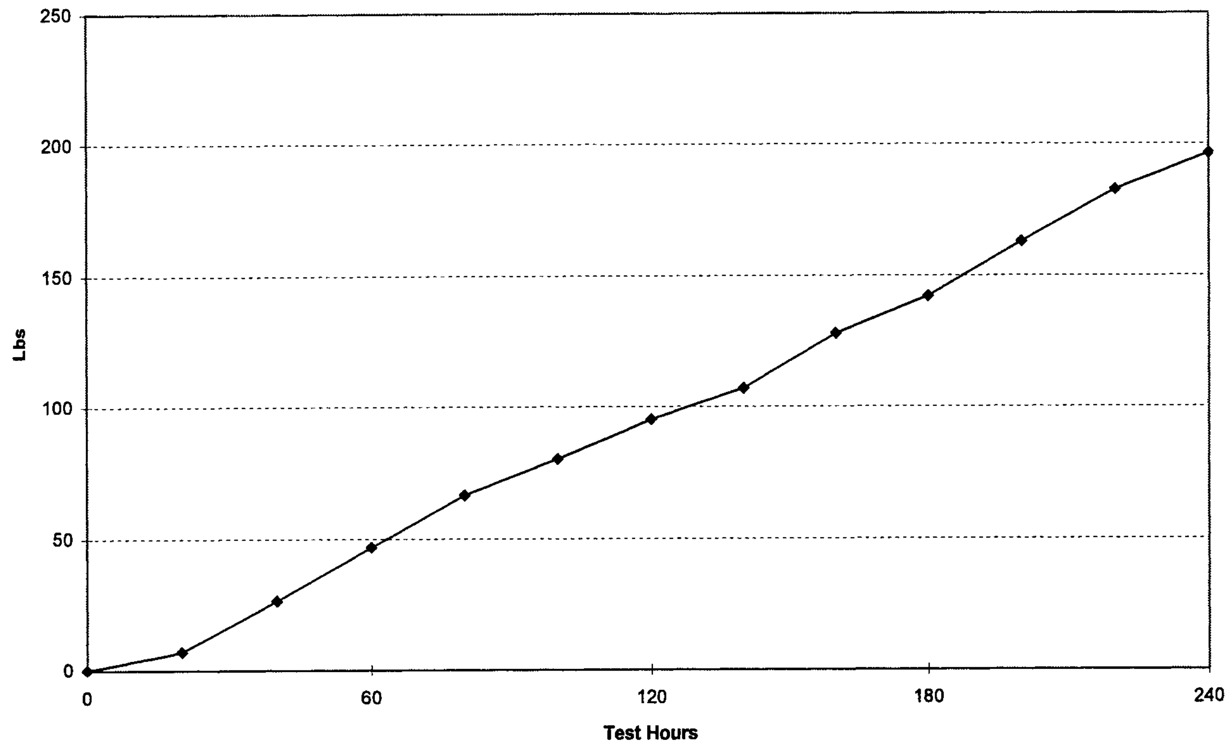


Figure D-6. Cumulative Oil Consumption

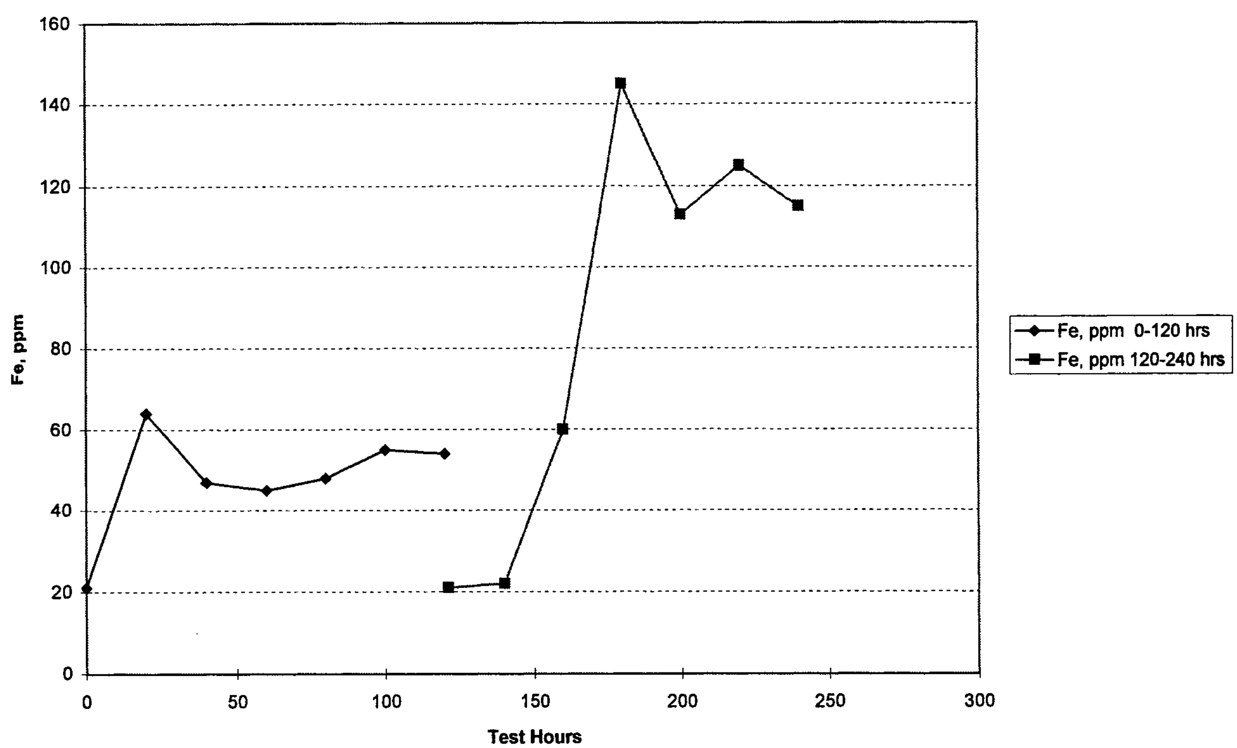


Figure D-7. Used Oil Iron Content

6V-53T
Test 60
WEAR MEASUREMENTS*
Lubricant: AL-24867-L/AL-20241-L

Cylinder Liner Bore Diameter Change**

	1L		2L		3L	
	T-AT**	F-B	T-AT	F-B	T-AT	F-B
Top	0.0005	0.0008	0.0018	0.0001	0.0015	-0.0002
Middle	0.0008	0.0008	0.0012	0.0008	0.0012	0.0007
Bottom	0.0008	-0.0004	0.0003	0.0013	0.0002	0.0012

	1R		2R		3R	
	T-AT	F-B	T-AT	F-B	T-AT	F-B
Top	0.0018	0.0001	0.0199	0.0218	0.0014	0.0005
Middle	0.0013	0.0010	0.0167	0.0183	0.0012	0.0007
Bottom	0.0008	0.0012	0.0006	0.0006	0.0006	0.0012

	Average Change	
	T-AT	F-B
Top	0.0045	0.0038
Middle	0.0037	0.0037
Bottom	0.0006	0.0009

Overall average change: 0.0029

Piston Ring End Gap Change

Ring Number	1L	2L	3L	1R	2R	3R	Average
1	0.004	0.005	0.006	0.000	0.010	0.007	0.005
2	0.002	0.002	0.001	0.004	0.004	0.001	0.002
3	0.001	0.000	0.001	0.001	0.000	0.001	0.001
4	0.002	0.001	0.001	0.001	0.001	0.002	0.001
5	0.008	0.009	0.006	0.009	0.014	0.01	0.009
6	0.004	0.005	0.004	0.005	0.003	0.003	0.004
7	0.005	0.004	0.004	0.005	0.005	0.004	0.005

Overall average change: 0.0039

Average Piston Ring Radial Width Change

Ring Number	1L	2L	3L	1R	2R	3R	Average
1	0.0352	0.03516	0.03550	0.03492	0.03510	0.03624	0.03535
2	0.0354	0.03536	0.03562	0.03604	0.03570	0.02978	0.03465
3	0.03506	0.03528	0.03502	0.03582	0.03502	0.03624	0.03541
4	0.03544	0.14932	0.03510	0.03590	0.03736	0.03542	0.05476

Overall average change: 0.0400

Bearing Weight Change

Main Bearings	1	2	3	4	Average
Upper	0.0085	0.1230	0.0203	0.0350	0.0467
Lower	0.0278	0.0414	0.0579	0.0466	0.0434

Overall average change: 0.0451

Rod Bearings	1L	2L	3L	1R	2R	3R	Average
Upper	0.0357	0.0368	0.0357	0.0374	0.0323	0.0437	0.0369
Lower	0.0080	0.0063	0.0090	0.0053	0.0066	0.0090	0.0074

Overall average change: 0.0222

*All dimensions are given in inches.
**T-AT=Thrust-Antithrust Direction; F-B= Front-Back Direction.

6V-53T
Test 60
POST TEST ENGINE CONDITION AND DEPOSITS
Lubricant: AL-24867-L/AL-20241-L

	Cylinder Number						
	1L	2L	3L	1R	2R	3R	Average
Cylinder Liner							
Intake Port Plugging, % restriction	0	0	0	0	0	0	0
Liner Scuffing, % Area							
Thrust	0.0	0.0	0.0	1.0	40.0	20.0	10.17
Anti-Thrust	25.0	12.0	18.0	5.0	45.0	10.0	19.17
%Total Area Scuffing	12.5	6.0	9.0	3.0	42.5	15.0	14.67
						Overall:	14.67
Bore Polishing, % Area							
Thrust	12.0	15.0	13.0	20.0	18.0	15.0	15.50
Anti-Thrust	5.0	25.0	15.0	26.0	18.0	15.0	17.33
%Total Area Polishing	8.5	20.0	14.0	23.0	18.6	15.0	16.52
						Overall:	16.52
Pistons							
Ring Face Distress, demerits							
No. 1	26.25	20.00	13.75	14.75	28.50	28.75	22.00
No. 2	27.50	27.50	25.00	23.75	20.25	36.25	26.71
No. 3	36.25	22.50	21.25	21.25	17.50	26.25	24.17
No. 4	25.00	21.25	22.50	20.50	25.00	25.00	23.21
						Overall:	24.02
Piston Skirt Rating*							
Thrust	LS	LS	LS	S	S	10% SC & S	
Anti-Thrust	S	LS	S	S	S	S	
Upper Oil Control Ring Expander Force (lbs)	19.50	19.50	19.00	19.58	20.28	20.20	19.68
Piston WTD Rating**	234.250	233.375	205.500	177.375	249.500	244.125	224.021
Ring Sticking***							
No. 1	70%CS	F	F	F	F	F	
No. 2	F	F	F	F	F	F	
No. 3	F	F	F	F	F	F	
No. 4	F	F	F	F	F	F	
Exhaust Valves							
Deposits****							
Head (MC, LC)	65, 35	60, 40	40, 60	40, 60	30, 70	25, 75	
Face (LC)	90	100	10	90	100	90	
Tulip (HC, MC, LC)	50, 50, n/a	30, 20, 50	50, 50, n/a	30, 50, 20	40, 40, 20	30, 50, 20	
Stem (LC), Laq.*****	10 , 1	10, 1	10, 1	10, 1	10, 1	10, 1	
Surface Condition							
Freeness in Guide							
Head (HC, MC, LC)	85, 15, n/a	95, 5, n/a	80, 20, n/a	90, 10, n/a	100, n/a, n/a	60, 30, 10	
Face	--------------------------Channeling (dirt particles embedded)-----------------------------						
Seat							
Stem******	LW	LW	LW	LW	LW	LW	
Tip	LW	LW	LW	LW	LW	LW	
Other Ratings							
Bearing Surface Condition							
Main Bearings	--Normal--						
Rod Bearings	--Normal--						

* L=Light, S=Scratches, PM=Plating Melted, N=Normal, SC=Scuffing, B=Burn
** CRC Weighted Total Deposits (0 = least, 900 = most)
*** HS = Hot Stuck, CS = Cold Stuck, P = Pinched, F = Free, N= Normal, CH = Chipped, C = Collapsed
**** HC = Hard Carbon, MC= Medium Carbon, LC=Light Carbon
***** The higher the number, the darker the lacquer (0 = lightest, 9= darkest)
****** F = Free, N = Normal, LW = Light Wear

6V-53T
Test 60
FUEL INJECTOR TESTS
Fuel: AL-24855-F

	Cylinder Number						
	*1L	2L	3L	1R	2R	3R	Average
Pop-Off Pressure, Psi							
Before Test	138	142	148	146	136	144	142.3
After Test, Before Cleaning	132	134	140	138	<100	134	135.6
After Test, After Cleaning	136	138	144	142	<100	140	140.0
Spray Pattern							
Before Test	Good	Good	Good	Good	Good	Good	
After Test, Before Cleaning	Good	Good	Good	Good	Good	Good	
After Test, After Cleaning	Good	Good	Good	Good	Good	Good	
Tip Dryness							
Before Test	Normal	Normal	Normal	Normal	Normal	Normal	
After Test, Before Cleaning	Normal	Normal	Normal	Normal	Normal	Normal	
After Test, After Cleaning	Normal	Normal	Normal	Normal	Normal	Normal	
Leak Down Time, sec.							
Before Test	44	48	76	24	26	35	42.2
After Test, Before Cleaning	40	46	52	15	26	25	34.0
After Test, After Cleaning	34	31	108	13	24	27	39.5
Fuel Pump Calibration (cc/1000 stks)							
Before Test	98	98	98	98	98	98	98.0
After Test, Before Cleaning	96	96	96	96	95	98	96.2
After Test, After Cleaning	96	96	96	96	92	96	95.3

**Seized 53.5 hrs.

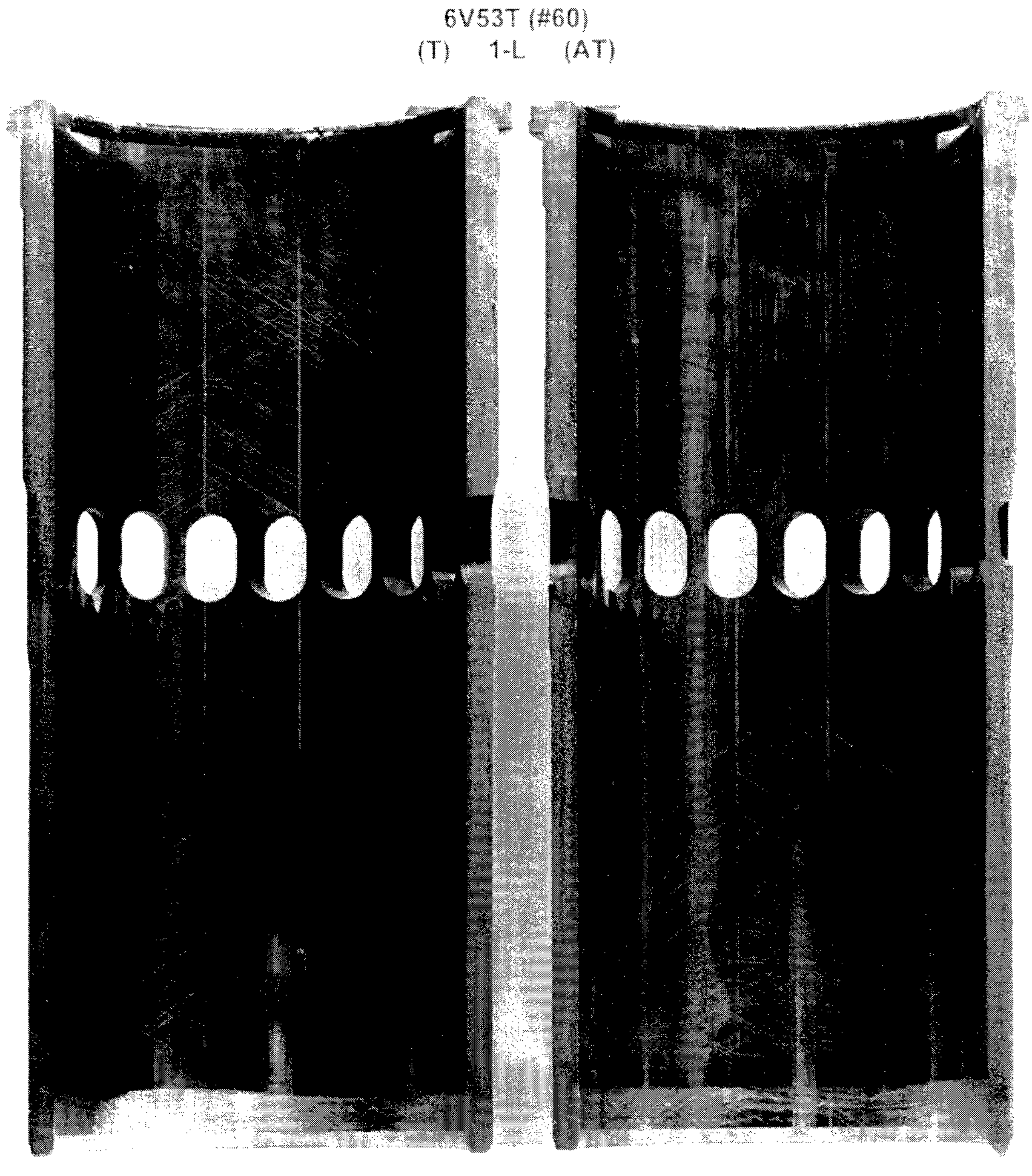


Figure D-8. <u>**6V53T Test 60, Liner 1-L**</u>

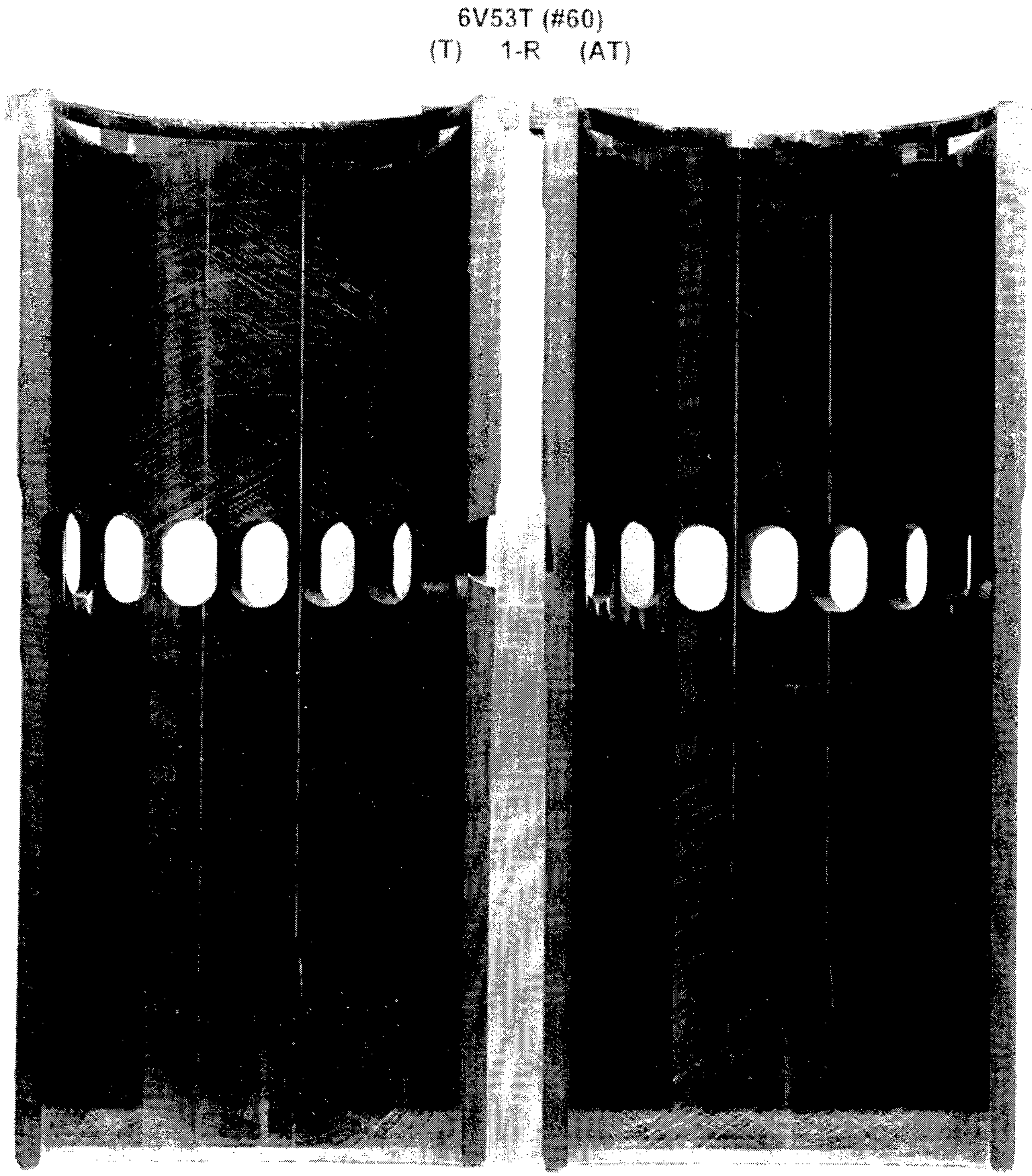


Figure D-9. **<u>6V53T Test 60, Liner 1-R</u>**

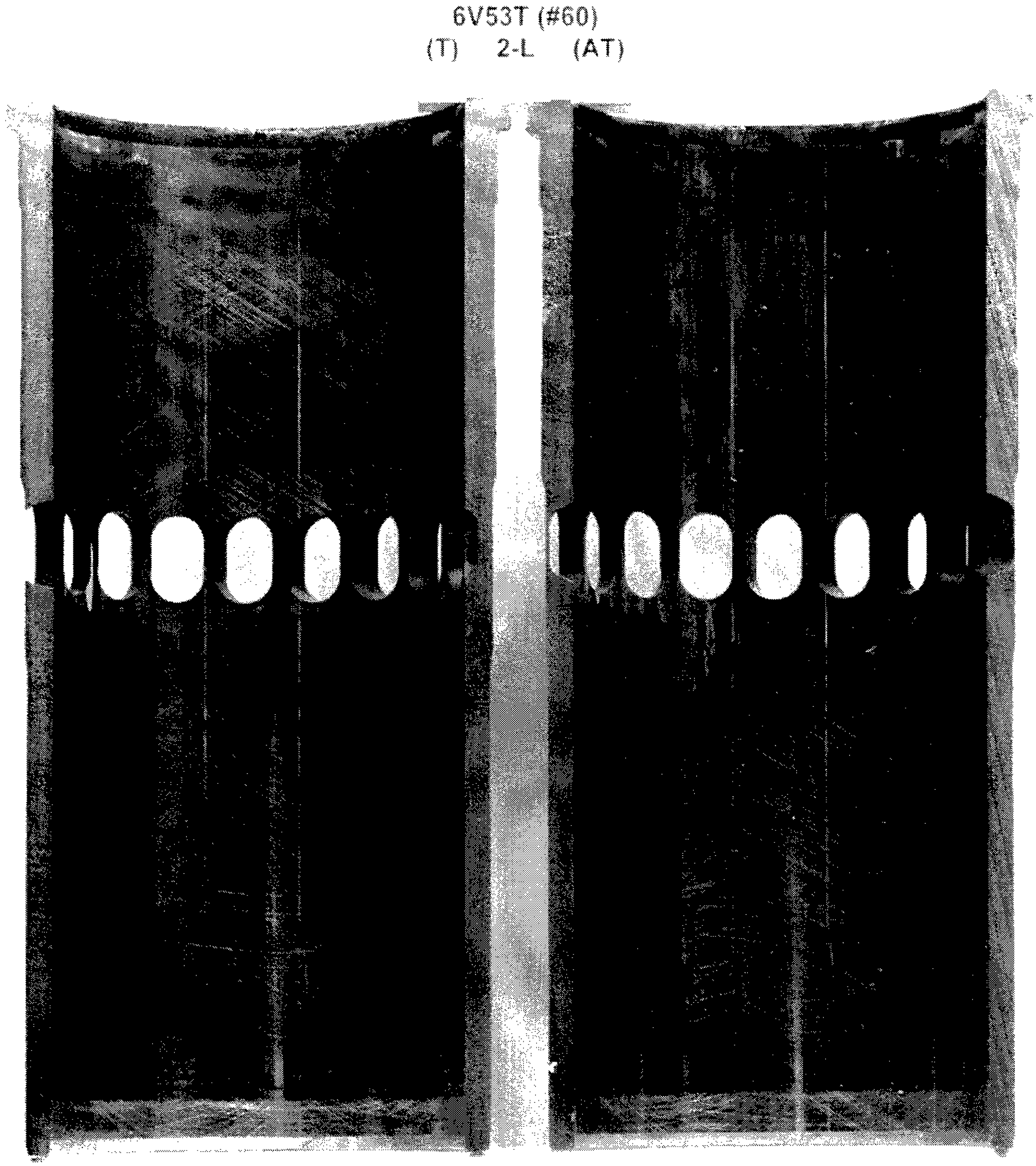


Figure D-10. <u>6V53T Test 60, Liner 2-L</u>

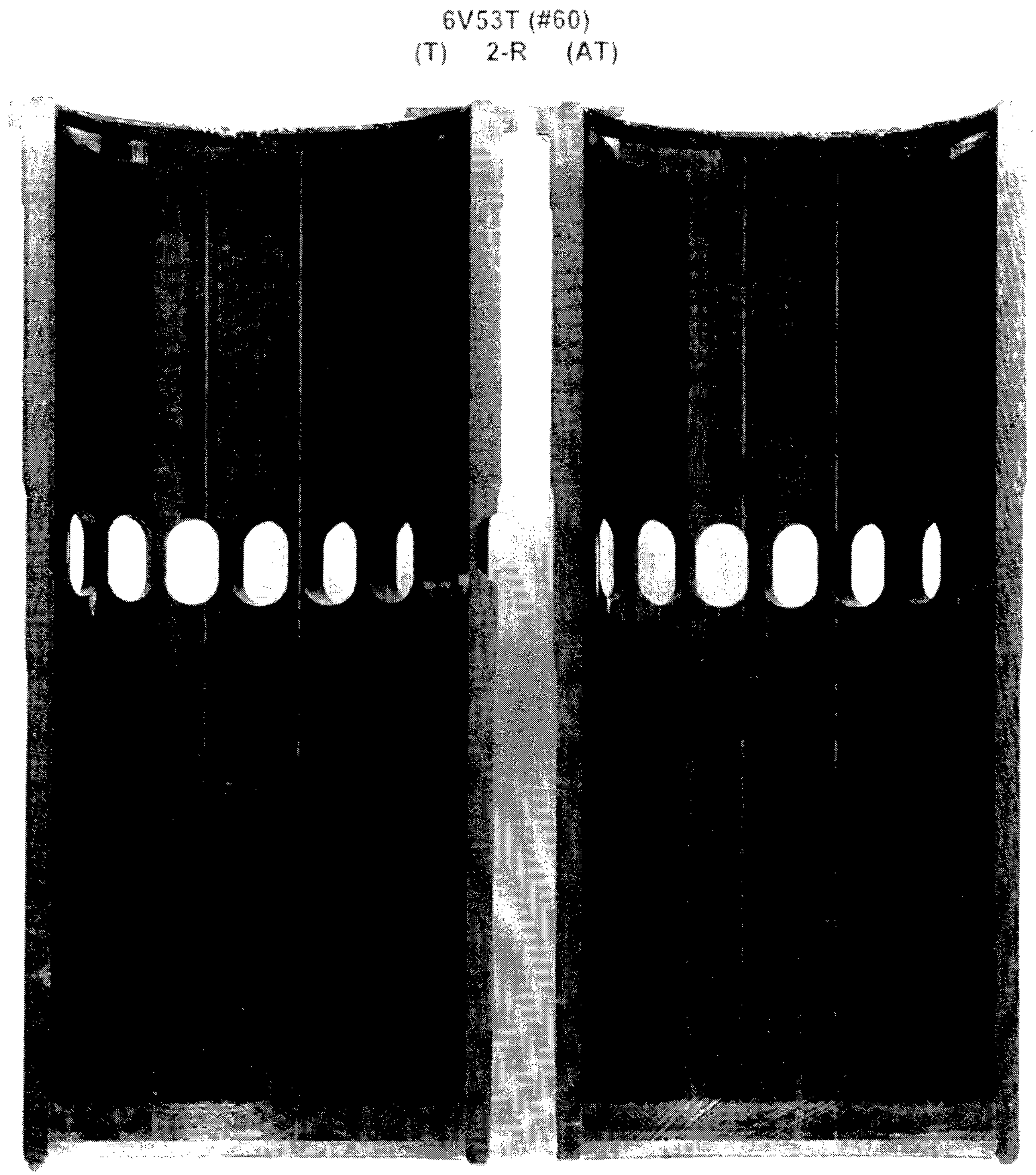


Figure D-11. __6V53T Test 60, Liner 2-R__

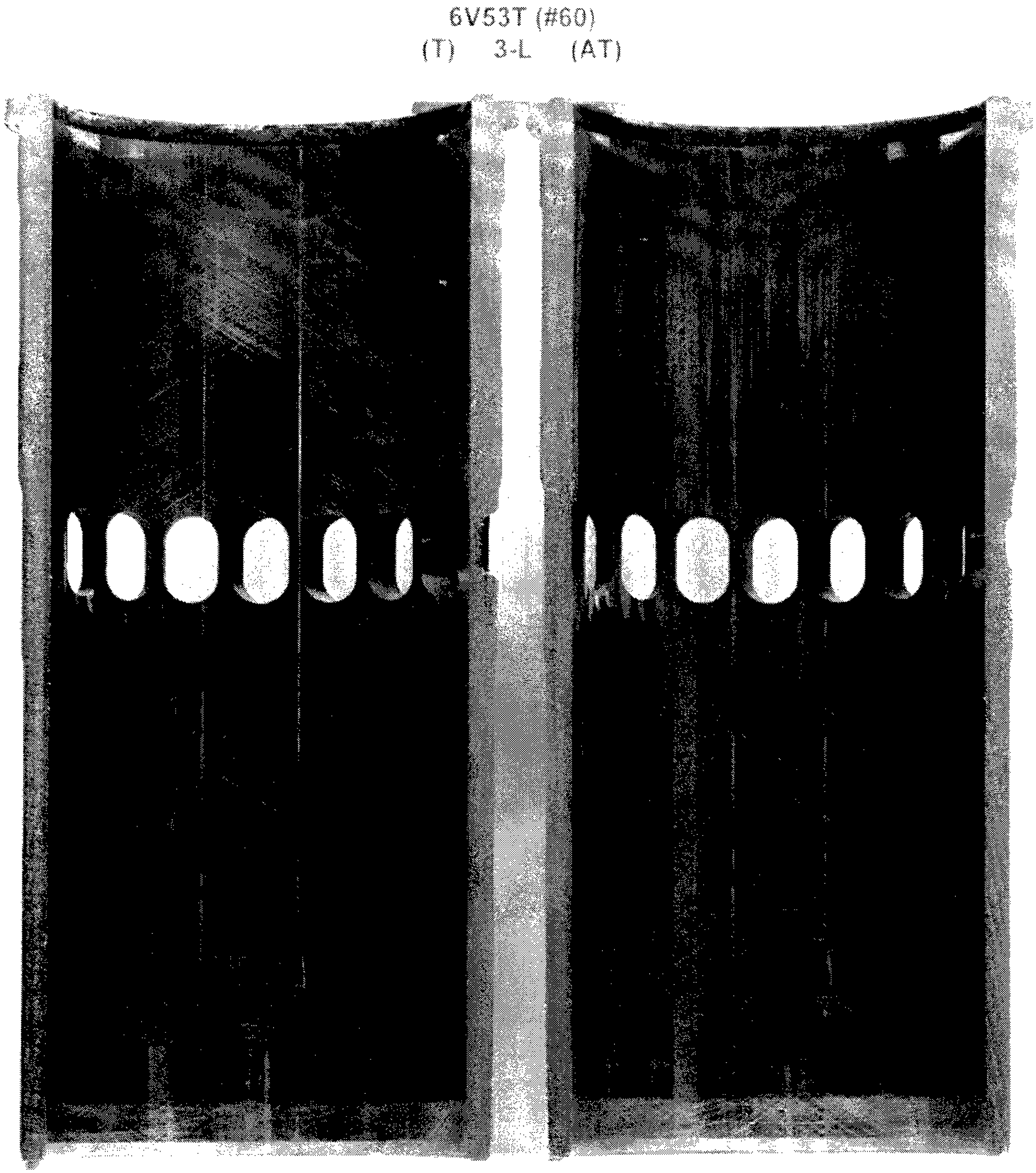


Figure D-12. <u>6V53T Test 60, Liner 3-L</u>

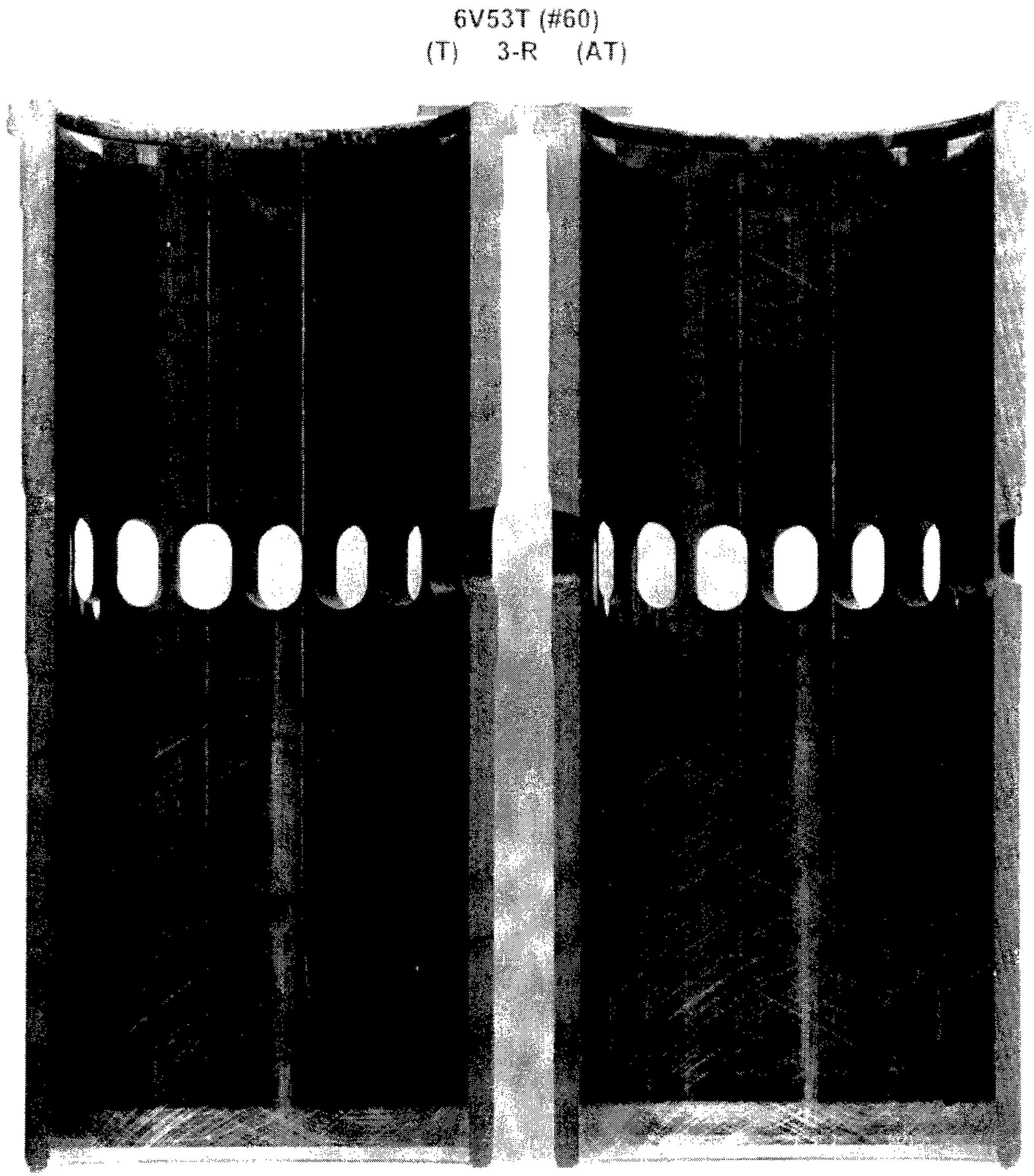


Figure D-13. <u>**6V53T Test 60, Liner 3-R**</u>

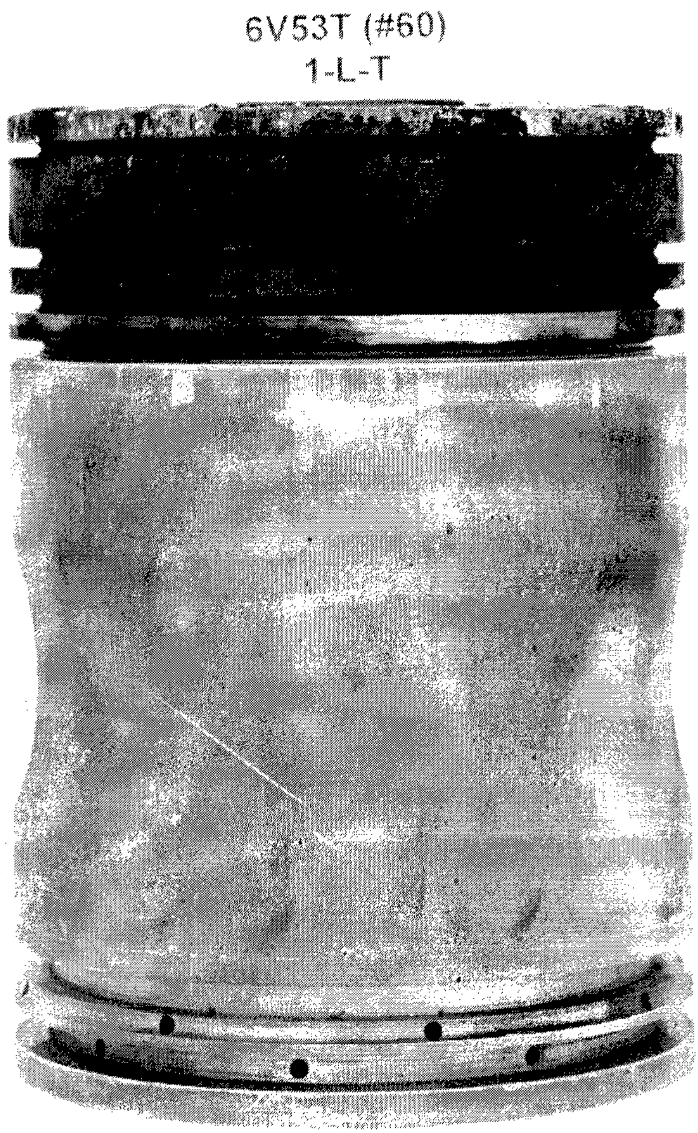


Figure D-14. **<u>6V53T Test 60, Piston 1-L-T</u>**

Figure D-15. **<u>6V53T Test 60, Piston 1-L-AT</u>**

Figure D-16. 6V53T Test 60, Piston 1-R-T

Figure D-17. 6V53T Test 60, Piston 1-R-AT

Figure D-18. **<u>6V53T Test 60, Piston 2-L-T</u>**

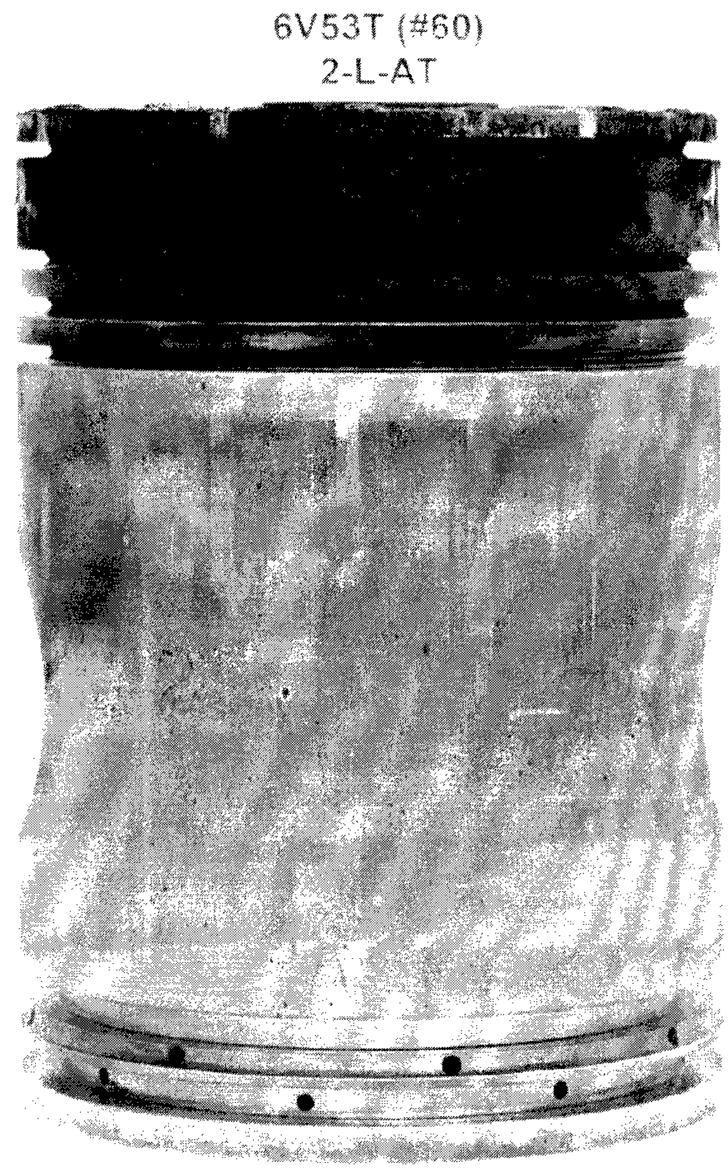


Figure D-19. **<u>6V53T Test 60 Piston 2-L-AT</u>**

Figure D-20. <u>6V53T Test 60, Piston 2-R-T</u>

Figure D-21. <u>6V53T Test 60 Piston 2-R-AT</u>

6V53T (#60)
3-L-T

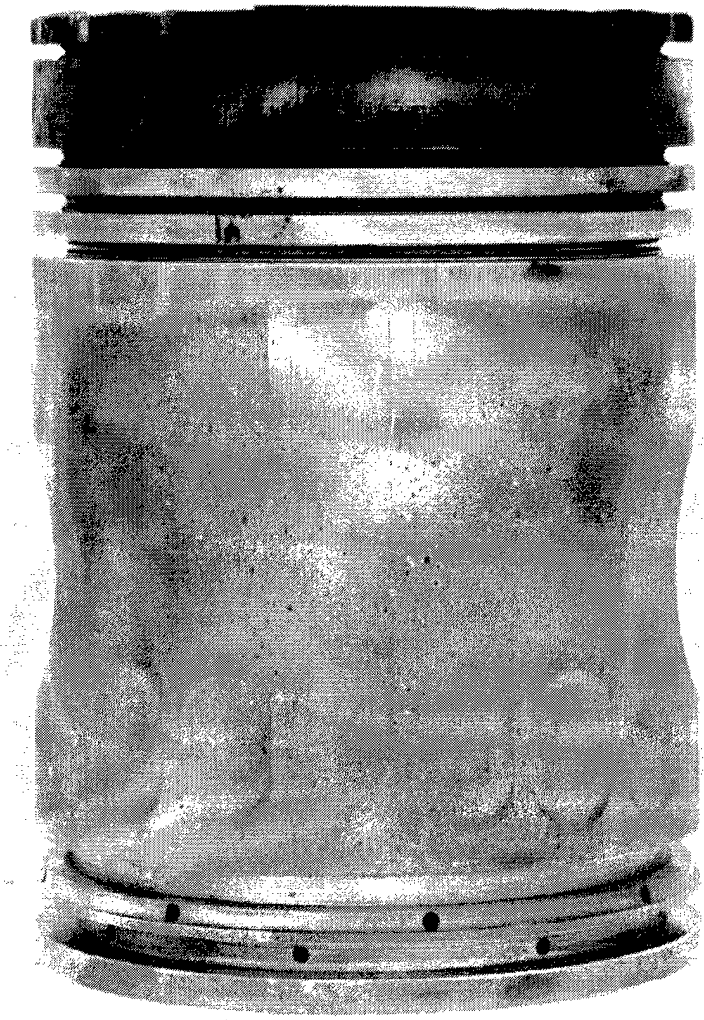


Figure D-22. 6V53T Test 60, Piston 3-L-T

6V53T (#60)
3-L-AT

Figure D-23. 6V53T Test 60, Piston 3-L-AT

Figure D-24. 6V53T Test 60, Piston 3-R-T

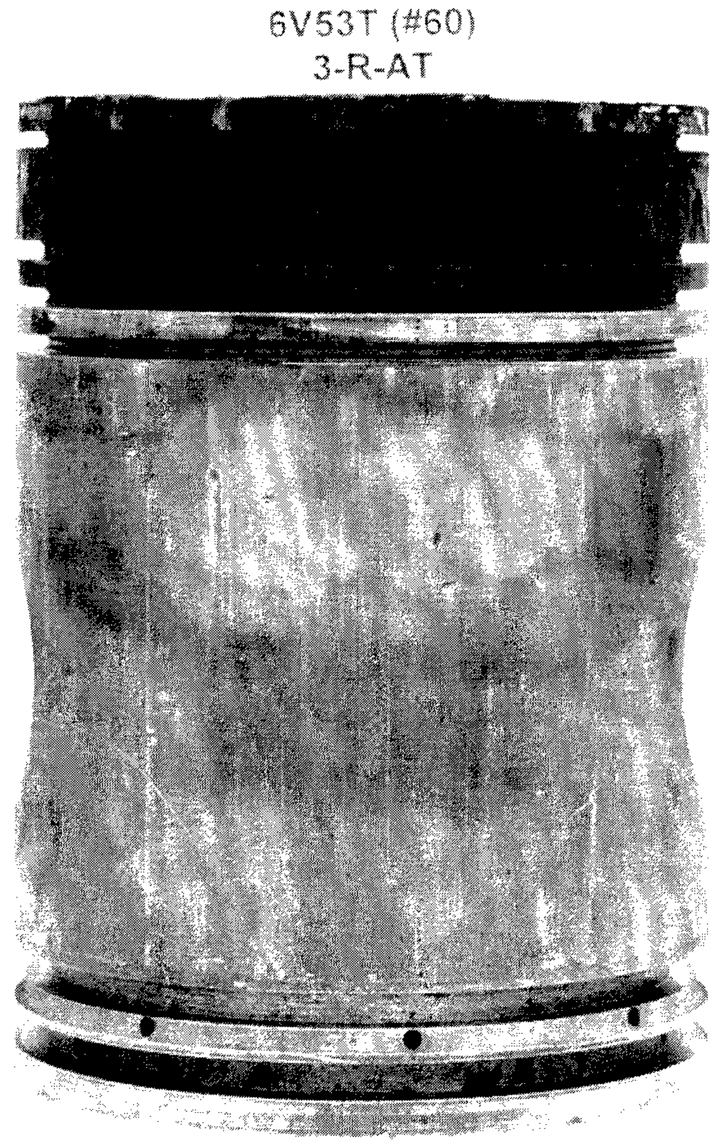


Figure D-25. 6V53T Test 60, Piston 3-R-AT

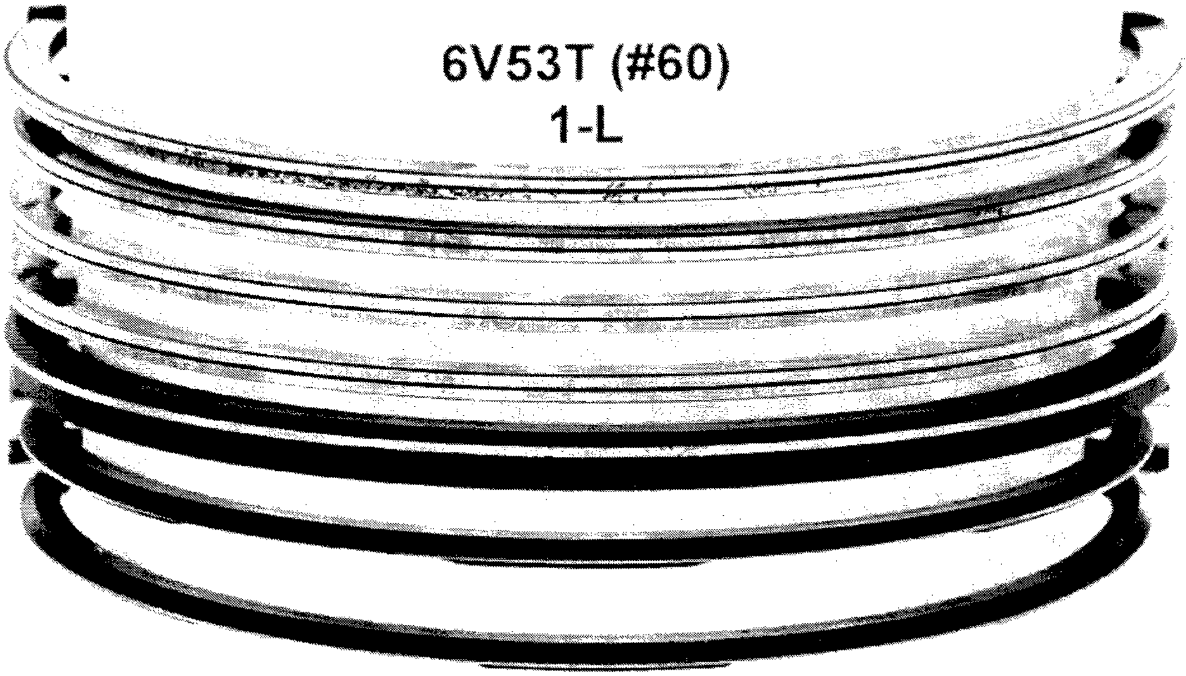


Figure D-26. **<u>6V53T Test 60, Cylinder 1-L, Rings</u>**

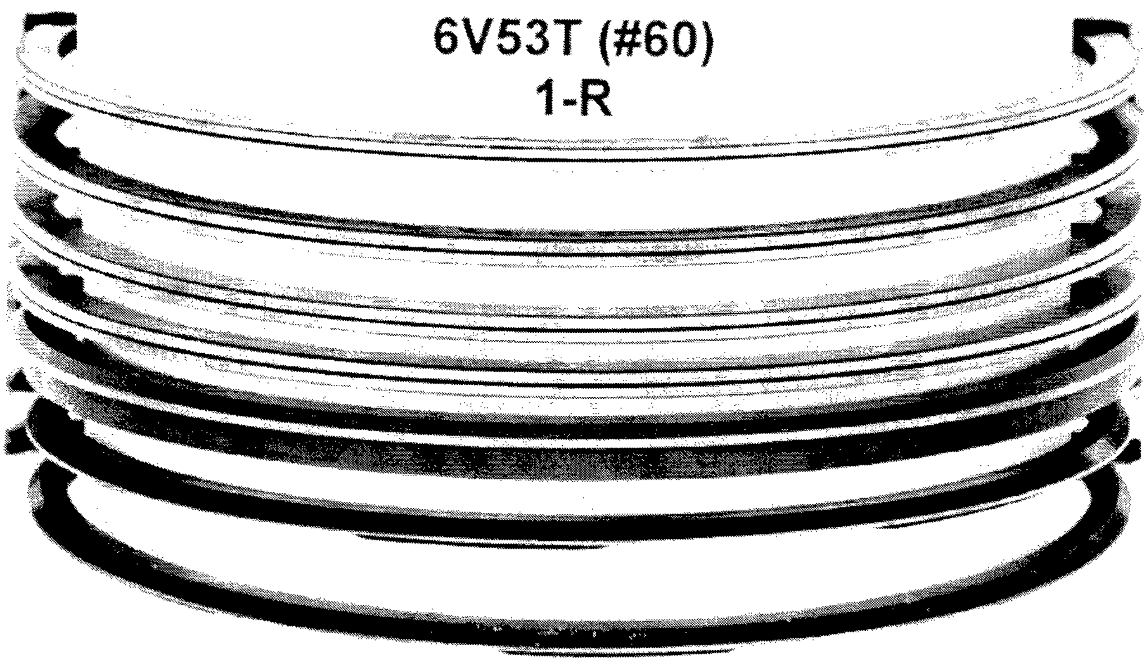


Figure D-27. **<u>6V53T Test 60, Cylinder 1-R, Rings</u>**

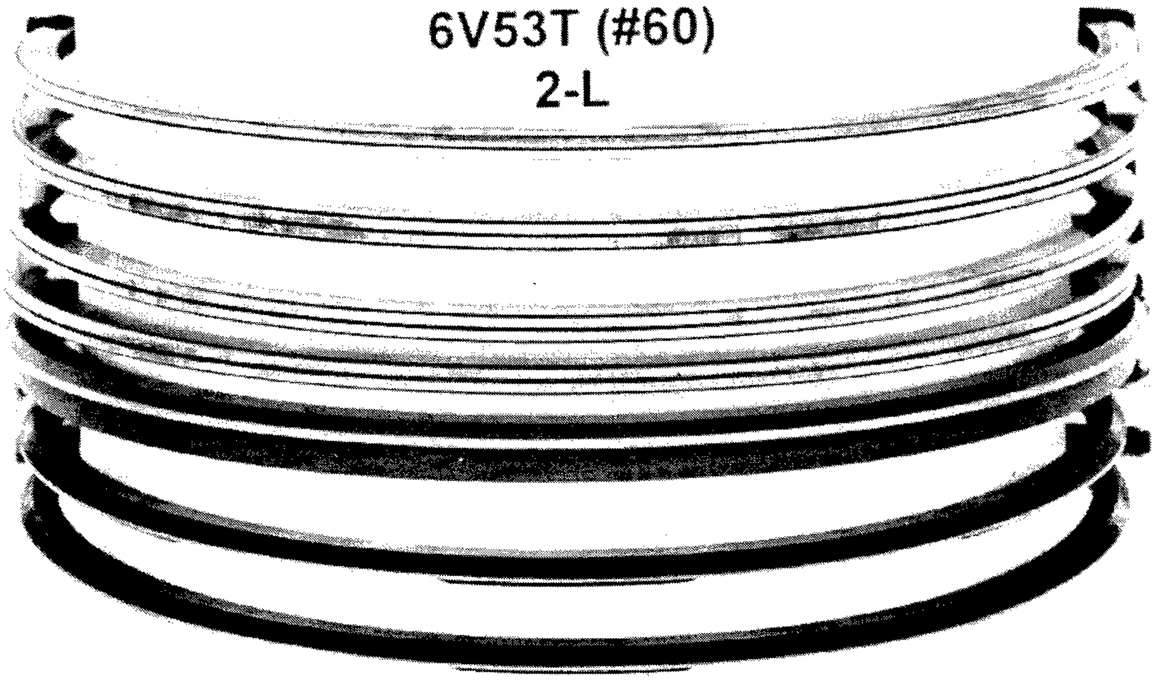


Figure D-28. <u>**6V53T Test 60, Cylinder 2-L, Rings**</u>

Figure D-29. <u>**6V53T Test 60, Cylinder 2-R, Rings**</u>

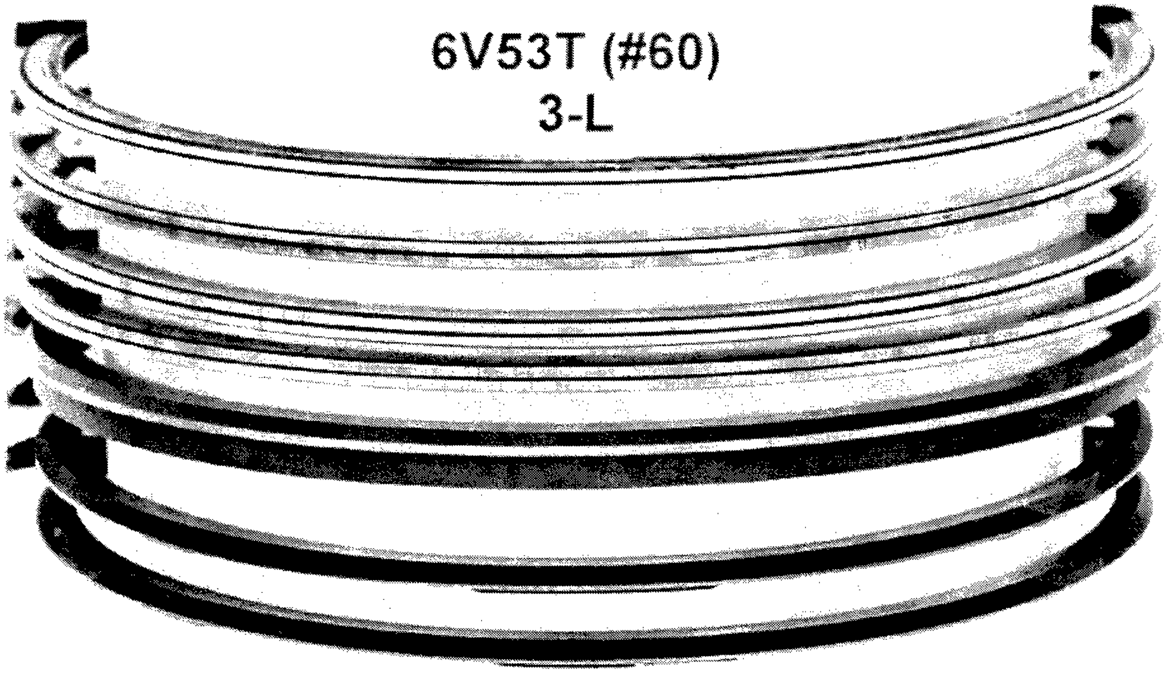


Figure D-30. **<u>6V53T Test 60, Cylinder 3-L, Rings</u>**

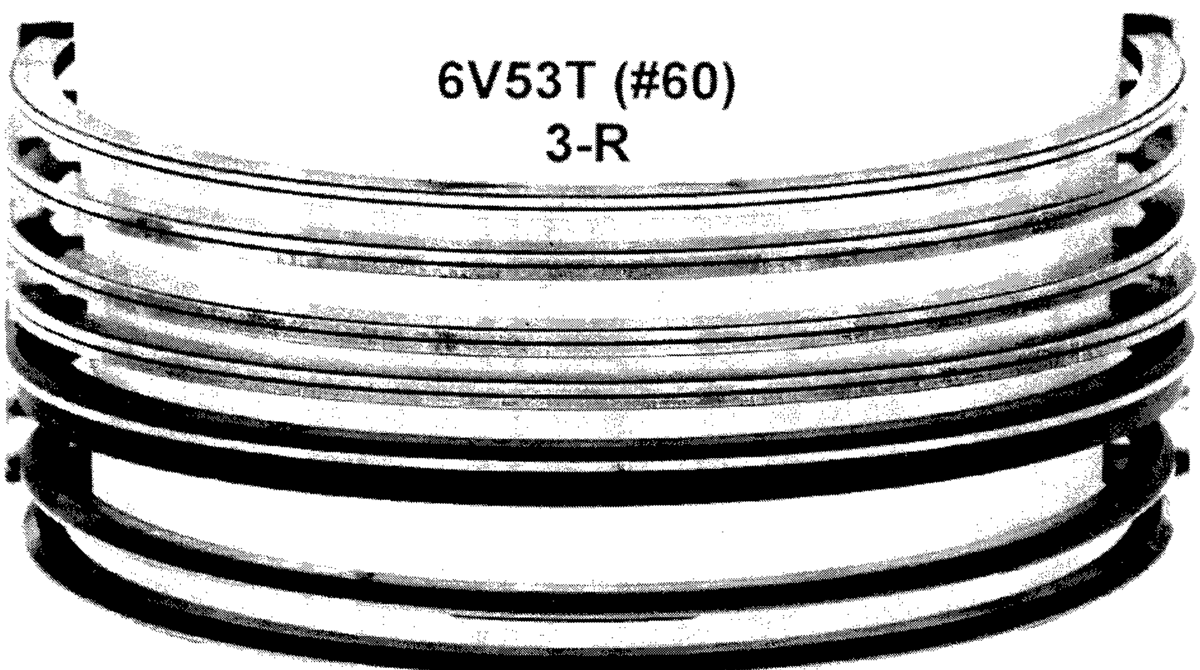


Figure D-31. **<u>6V53T Test 60, Cylinder 3-R, Rings</u>**

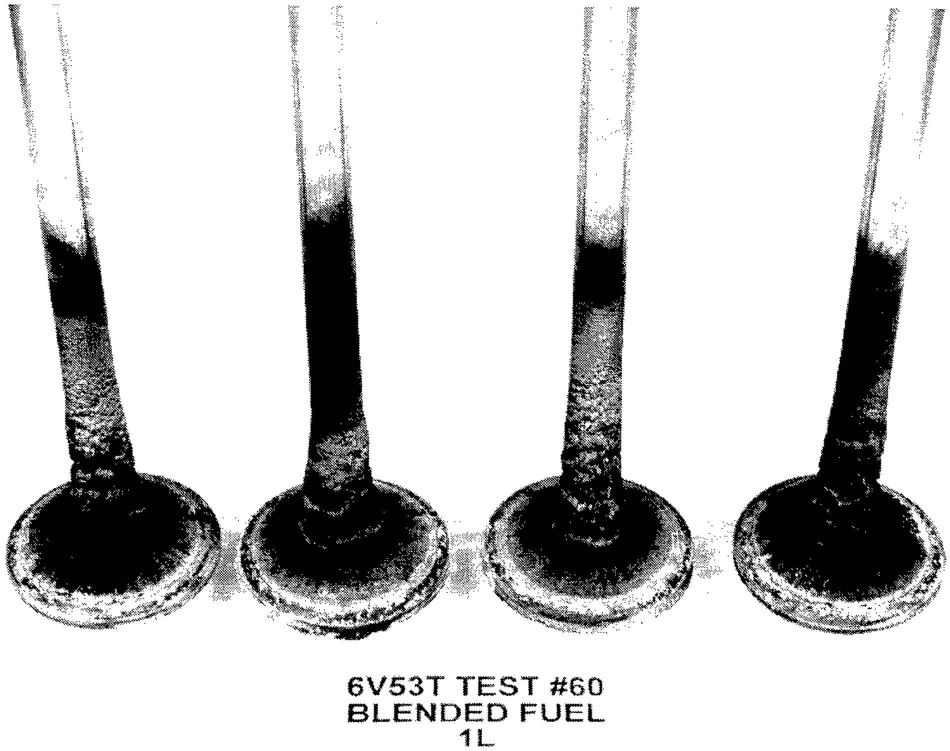


Figure D-32. <u>6V53T Test 60, Cylinder 1-L, Valves</u>

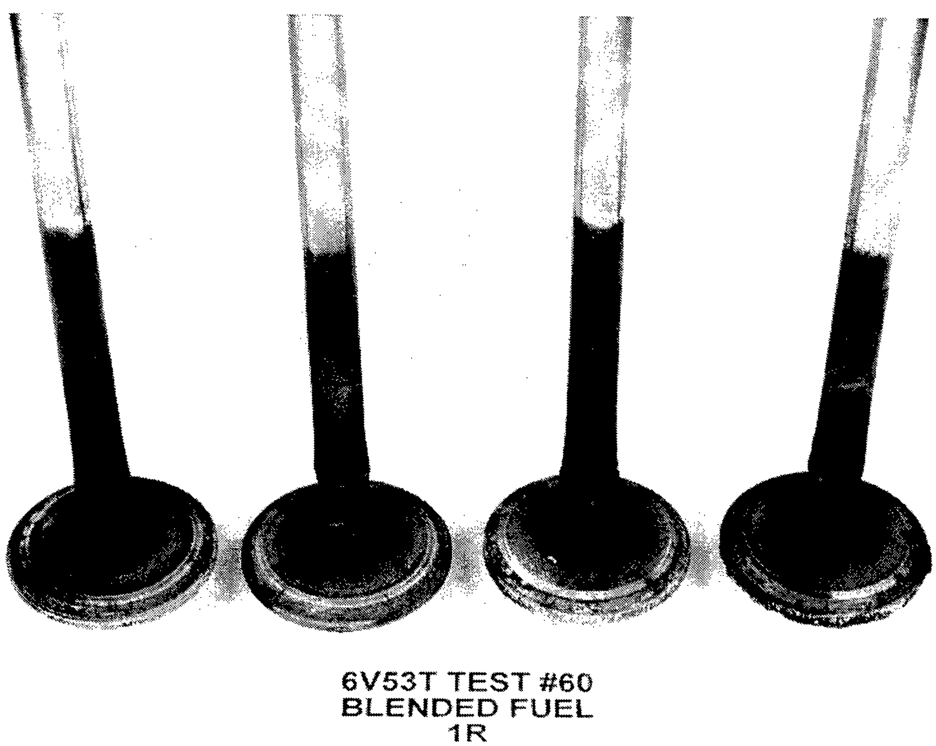


Figure D-33. <u>6V53T Test 60, Cylinder 1-R, Valves</u>

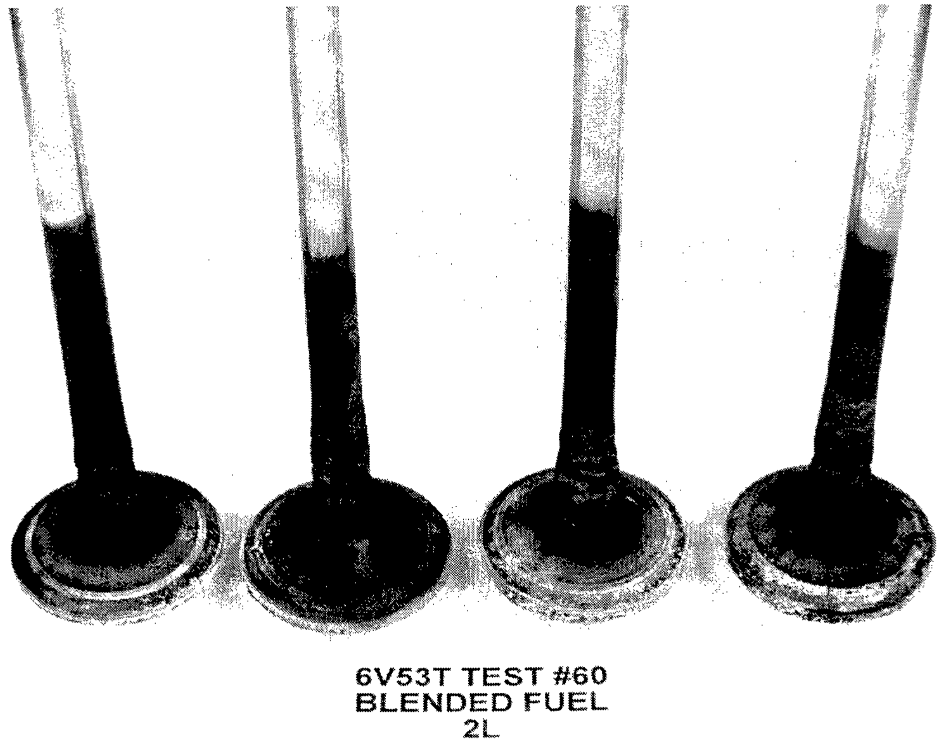


Figure D-34. 6V53T Test 60, Cylinder 2-L, Valves

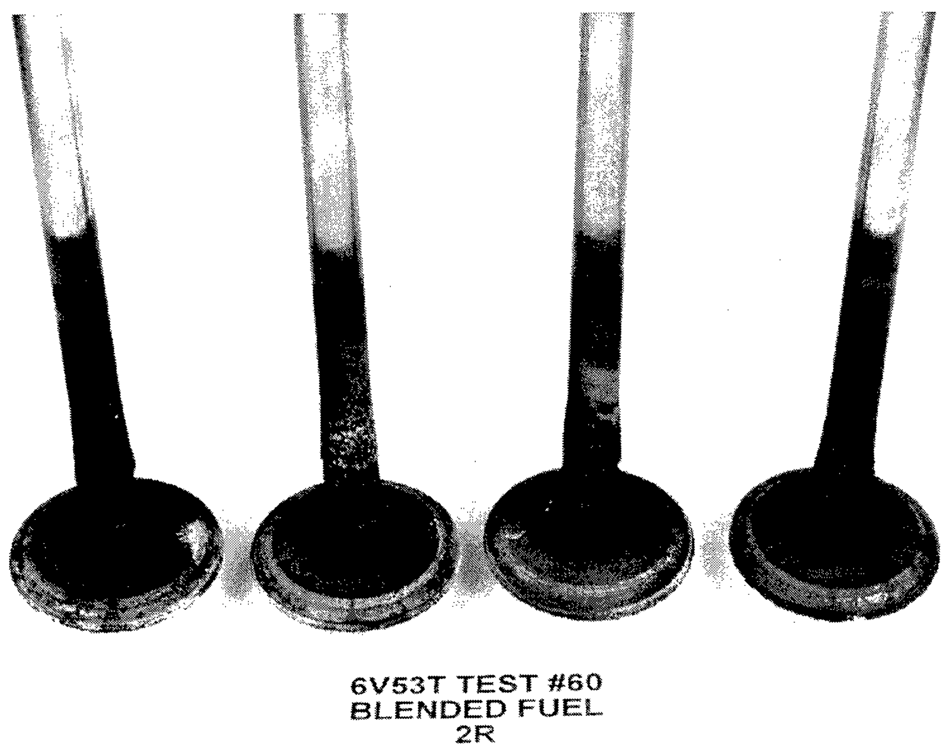


Figure D-35. 6V53T Test 60, Cylinder 2-R, Valves

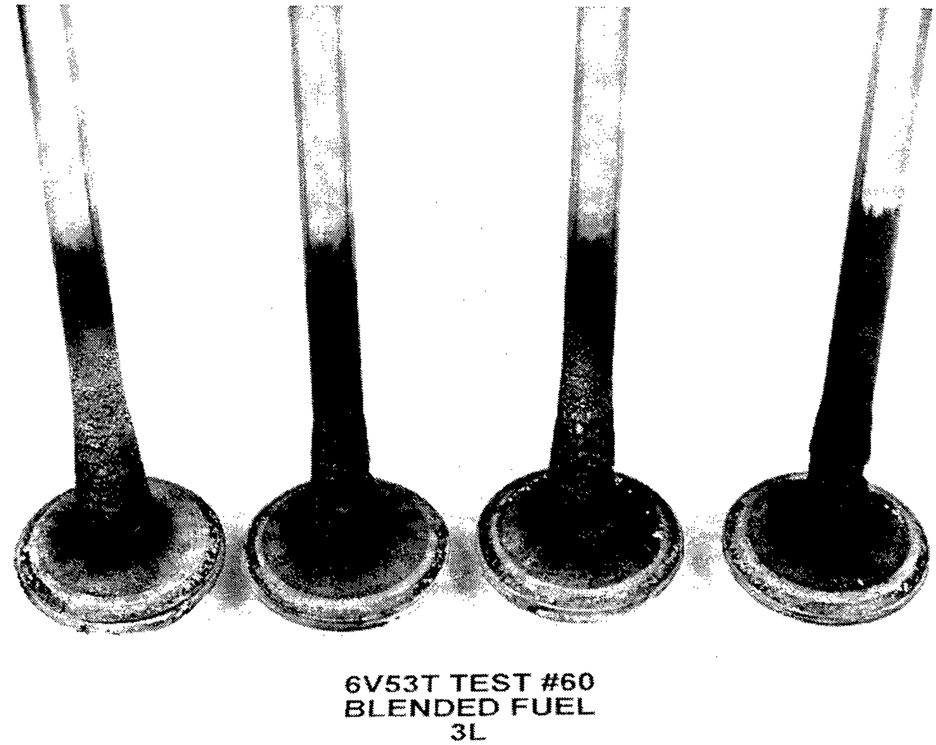


Figure D-36. 6V53T Test 60, Cylinder 3-L, Valves

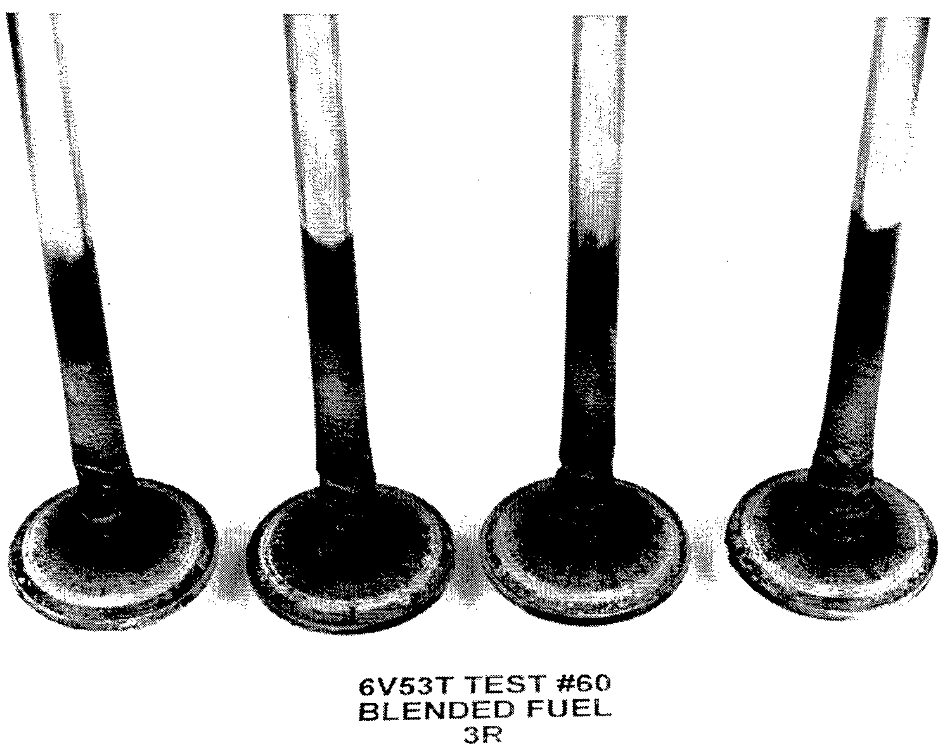


Figure D-37. 6V53T Test 60, Cylinder 3-R, Valves

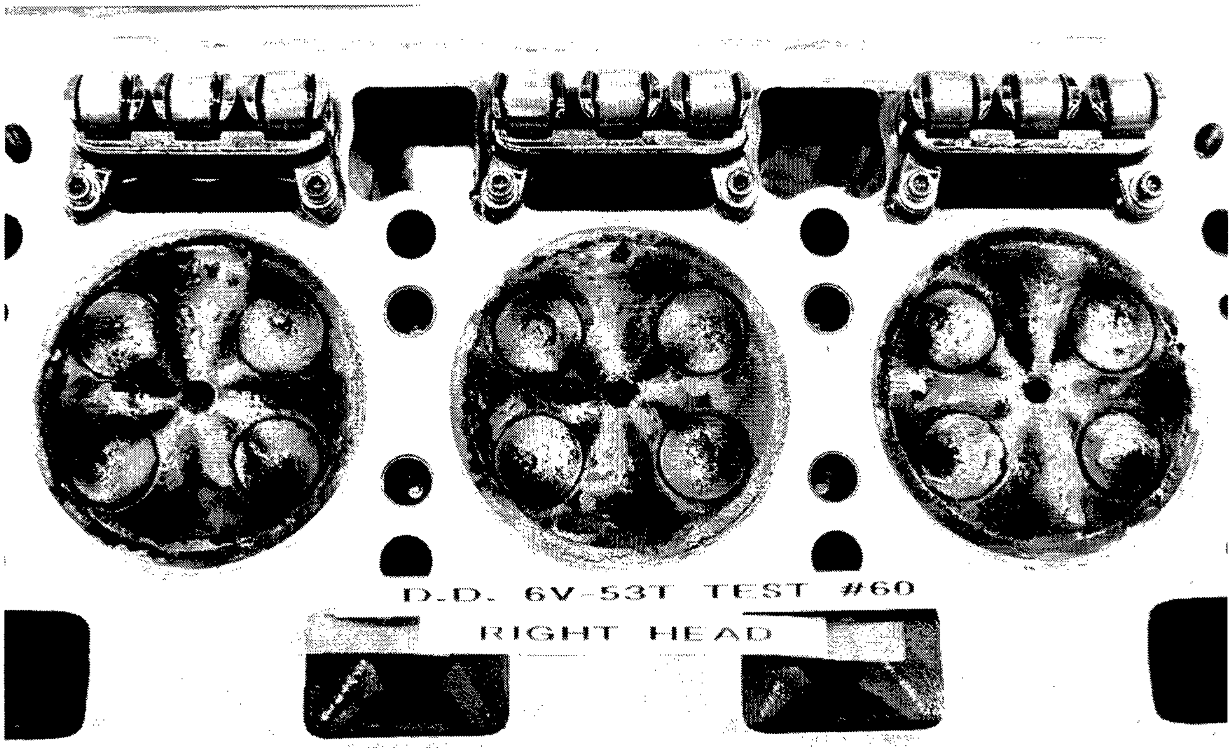


Figure D-38. <u>6V53T Test 60, Right Head</u>

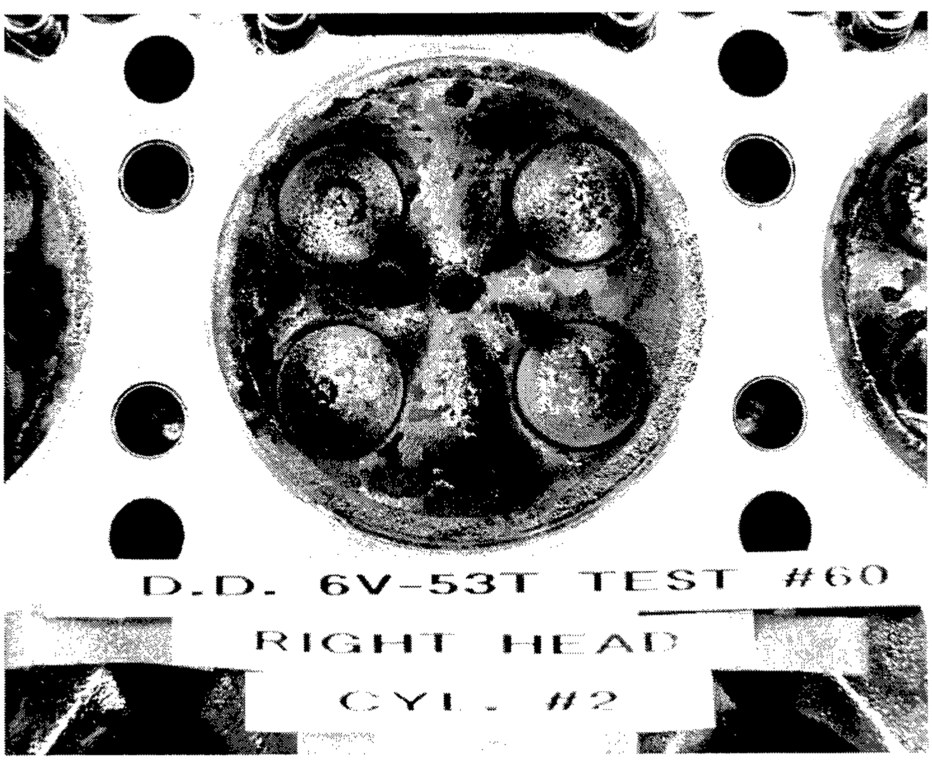


Figure D-39. <u>6V53T Test 60, Right Head, Cylinder No. 2</u>

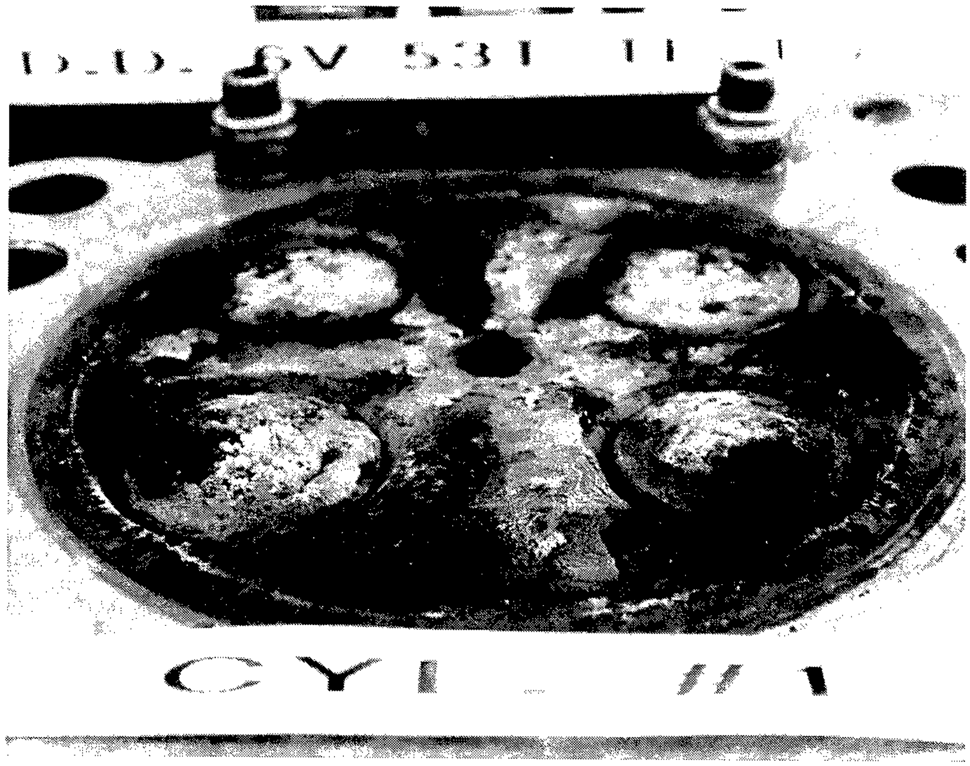


Figure D-40. 6V53T Test 60, Cylinder No. 1

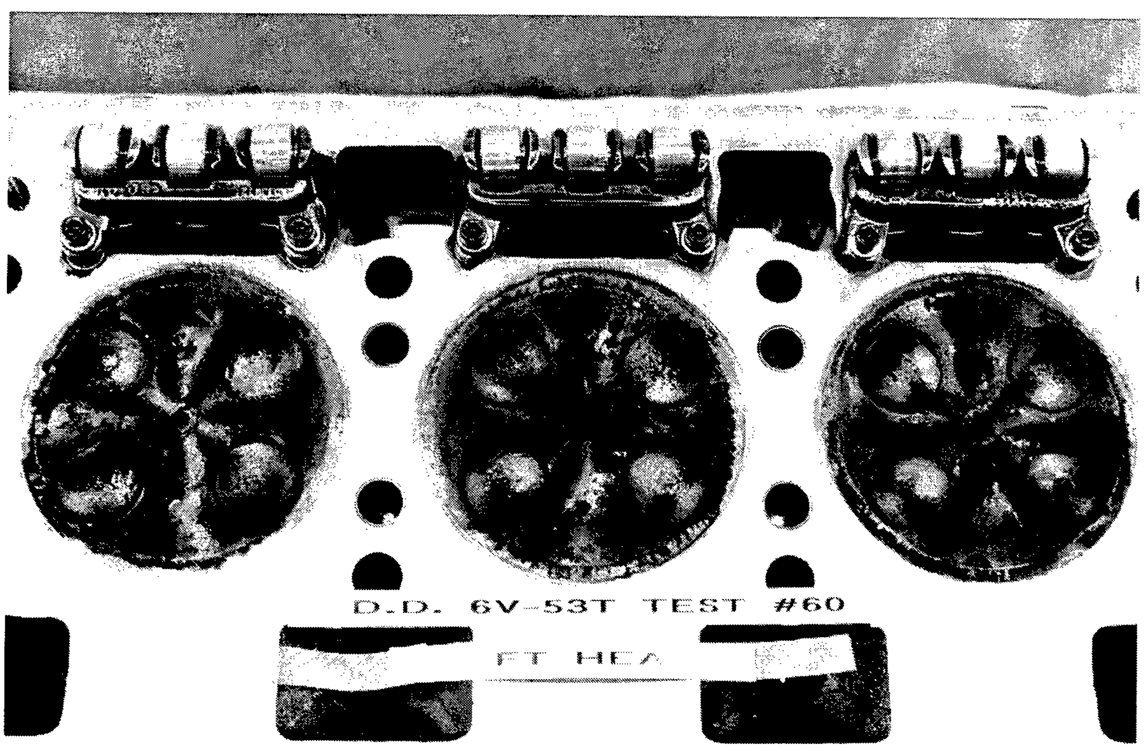


Figure D-41. 6V53T Test 60, Left Head

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AMSTA TR M 1
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